RIVER FEATURES ASSOCIATED WITH CHUM SALMON SPAWNING AREAS: A METHOD TO ESTIMATE HABITAT CAPACITY

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A

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Abstract

Diminishing returns of salmon and years of poor commercial and subsistence fishing in western Alaska are a cause for concern. Management tools which recognize the intricate life histories of salmon and incorporate environmental conditions at each particular life stage are needed. Toward that goal a study of spawning habitat for chum salmon Oncorhynchus keta was conducted from 2002 to 2005 on the Tuluksak River in western Alaska. Small-scale river features were measured during two summers of field work. Large-scale river features were identified using remote sensing. Principal components analysis (PCA) denoted an association between spawning sites and channel intersections, gravel bars, islands, and areas of accelerated channel change, forming the basis for a predictive habitat model. Two models were developed that combined the habitat assessment with chum salmon redd size and spatial requirements at three spawning densities. The first model, based on field observations in 2002 and 2003, estimated a greater spawning capacity than the second model, based on large-scale river features. Spawning capacity estimates from both models were consistent with historic escapement data and should be used as a starting point for further research. This study represents progress toward a management strategy that is sensitive to habitat-dependent production potential.

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Introduction

Salmon stocks in western Alaska are the cornerstone of the region's rural economy (University of Alaska 1992), in terms of both subsistence and commercial ventures. Salmon have a cultural and spiritual dimension which supports a traditional and nascent way of life in bush Alaska (Wolf and Zuckerman 2003). Beyond these human values, salmon are good ecological indicators. Salmon transport energy in the form of nutrients both to the sea (Scheuerell et al. 2005) where they are a major player in complex marine food webs, and inland (Kline et al. 1993) where they physically alter the structure of their spawning habitat (Montgomery et al 1999) and enrich the productivity of aquatic and terrestrial systems (Helfield and Naiman 2001). Clearly the conservative management of such a valuable resource is paramount. Incomplete baseline fishery data and limited spawning escapement data for the Kuskokwim River drainage have hindered successful management (Kenai Fishery Assistance Office 1992) and spurred the development of alternate methods that account for the stages of a complex life history (Mobrand et al. 1997).

Recent events in western Alaska, most notably, several poor fishing years in the 1997 and 1998 fishing seasons and the collapse of the market value for wild-caught Alaskan salmon worldwide have prompted increased scrutiny in the methods used to manage today's salmon stocks (Kruse 1998). The Ricker model (Ricker 1954), while effective, has inherent limitations (National Research Council 1996). First, Ricker stock-recruitment models work best when used with long-term data, which often are necessarily collected subsequent to the establishment of intense fisheries (Knudsen et al. 2003).

There are no long-term data sets available to analyze the effect of this type of management. Second, model indices including aerial counts, weir counts, and test-fishery data are collected after the commencement of a particular stock's spawning run. Hence any intervening management actions may occur too late in the season to prevent over-harvest. Thirdly, an increase in the knowledge about salmon life history has paved the way for the consideration of other management alternatives, including the assessment of system carrying capacity and habitat based population models. Escapement goals developed from specific habitat and/or life history data (Knudsen et al. 2003) recognize the ecosystem nutrient value of spawning salmon. Chum salmon *Oncorhynchus keta* are an ideal candidate to test the efficacy of habitat-based escapement goals. They exhibit a strong homing behavior (Groot and Margolis 1991) and their critical reproductive life stages are directly habitat-dependent.

This study examined the spawning habitat use of adult chum salmon in the Tuluksak River drainage. This was done to see if an estimate of spawning capacity could be derived for this chum salmon stock. In the interest of simplicity, and for the purposes of this study, the terms habitat-based escapement goal and spawning habitat capacity are used interchangeably and defined as an estimate of the number of adult salmon whose spatial and habitat criteria needs are met by a stream, river or part of a stream or river of a given size and dimension. These terms should not be confused with or interpreted as escapement goals as outlined by the Alaska Department of Fish and Game (ADF&G) and the Board of Fisheries in the Sustainable Salmon Fisheries Policy for the State of Alaska (5 AAC 39.22).

The availability of good salmon spawning areas, ones that meet the spawning capability of adults and in addition can shelter and incubate viable eggs, is limited by physical features such as substrate size, channel obstruction, water depth and flow. Available areas are preferentially selected by the spawning female salmon according to flow conditions (McNeil 1966) and other factors (substrate, cover, etc). For example, chum salmon have been widely recognized to spawn in areas of upwelling water (Volobuyev 1984; Groot and Margolis 1991; Geist, et al. 2002). Upwelling conditions are caused by channel-bed complexity (i.e. pool tail outs and riffle crests) or hyporheic flow to and from the river channel. Water can enter the stream bed at the downstream ends of pools and re-emerge at riffles further downstream (Poole and Berman 2001). Chum salmon have been described as "preferring to spawn immediately above turbulent areas (i.e. riffles) or where there is upwelling" (Groot and Margolis 1991). The affinity that chum salmon have for spawning sites that possess an upwelling component forms the basis and rationale for the detection of large-scale river features that foster such flow conditions.

Objectives of the study were twofold (1) to determine what river features were associated with spawning habitat for chum salmon of the Tuluksak River and (2) to provide a theoretical spawning capacity based on an assessment of spawning habitat availability toward improving escapement objectives in drainages such as the Tuluksak River where the data needed to form stock-recruit relationships are nonexistent or of limited duration and availability.

Study Site

The Tuluksak River is located in the Kuskokwim River drainage in western Alaska (Figure 1). The Yukon and Kuskokwim Rivers form a massive delta as they flow into the Bering Sea.

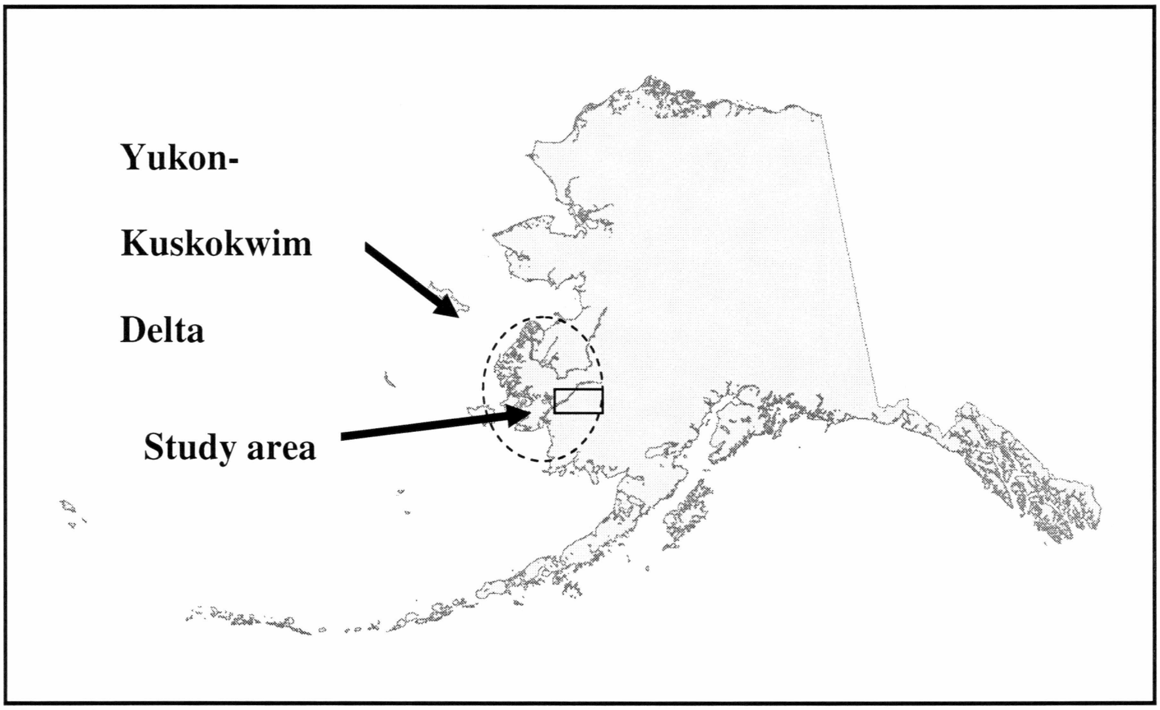

Figure 1. Map of Alaska and study site .

The Tuluksak River is one six or seven tributaries in the lower Kuskokwim River considered important spawning habitat for chum salmon (Mclean et al. 1977; Kenai Fishery Assistance Office 1992). The Tuluksak River flows into the Kuskokwim River 85 river kilometers (rkm) upstream of the town of Bethel and 192 rkm upstream from the mouth of the Kuskokwim River (Whitmore et al. 2005). Almost the entire length of the approximately 142-km Tuluksak River lies within the U.S. Fish and Wildlife Service (USFWS) Yukon Delta National Wildlife Refuge (YDNWR). The refuge is home to five

Pacific salmon species and it is well known as a waterfowl and shorebird rookery and haven. The tundra is inundated with small lakes and rivers and bordered by low mountains, the highest of which is 1,219 m (4,000 ft). The Kuskokwim Area includes the Kuskokwim River drainage, all waters of Alaska that flow into the Bering Sea between Cape Newenham and the Baskonat Peninsula, and Nunivak and St. Matthew Islands (ADF&G 2003). The Area has four commercial salmon fishing Districts: 1, 2, 4 and 5. The Tuluksak River is in District 1.

The Tuluksak River is a meandering stream that has low gradient, for all but the upper most reaches (Alt 1977). It flows through a lowland tundra area situated in discontinuous permafrost (Ferrians 1965). Flood plain surface geology is fluvial Pleistocene sediment and main features are abandoned terraces, oxbow lakes and paleochannels (extinct river channels that sometimes act as preferential flow pathways for groundwater). The riverbanks are partially forested, and the river flows through two vegetation zones beginning in gramminoid tundra and ending in sedge dominated wetlands (CAVM Team 2003). In spite of small-scale mining operations in the headwater areas, the river is largely a wild, pristine system.

A USFWS fish counting weir on the Tuluksak River has documented run timing, abundance, individual size, age, in-stream residence time, and sex ratio for chum, Chinook *Oncorhynchus tshawytscha*, coho *O. kisutch*, sockeye *O. nerka* and pink salmon *O. gorbuscha* (Harper 1995abc; Harper 1997; Gates and Harper 2002, 2003; Zabkar et al. 2005) for the years 1991-1994 and 2001-2005 (Figure 2). The chum salmon run begins the first week of June, peaks in late June to early July, and continues until mid-August.

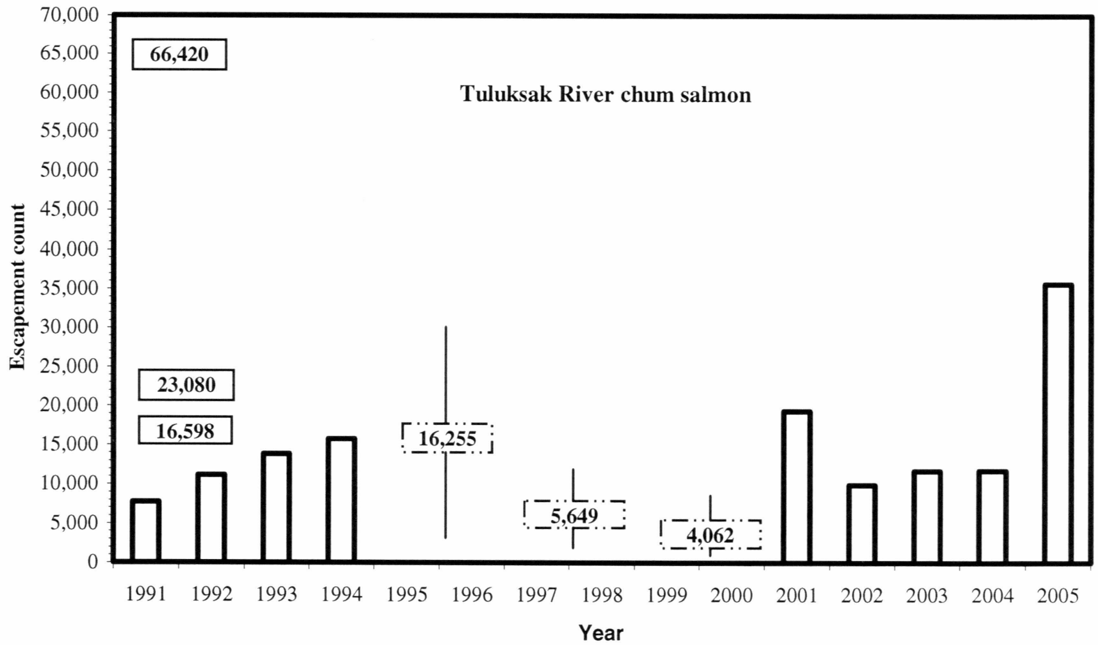

Figure 2. Tuluksak river chum salmon escapement estimates. Counts are based on weir data, 1991-1994 (Harper 1995abc, 1997) and 2001-2005(Gates and Harper 2002, 2003; Zabkar et al. 2005). No escapement data was collected from 1995 to 2000. Observed model spawning capacity estimates at high, medium, and low densities are in solid line boxes; predicted model capacity estimates at high medium and low densities are in dotted-line boxes and whiskers are 95% confidence intervals for each density. Note: observed and predicted model results are included for comparison with actual escapement estimates irrespective of year.

Chum salmon return to freshwater as sexually mature 2, 3, 4 and 5 year old fish, the brood years of the fish we observed in 2002 and 2003 were 1996, 1997, 1998, 1999, and 2000. The progeny of the 2002 and 2003 year classes began returning in 2004 and will continue to return until the last 5 year olds spawn in 2008. Out of 930 fish sampled in 2002 in all age categories, 54% were male and 46% were females (Gates and Harper 2003). Smith (1973) described criteria for upstream migration and spawning of Oregon chum salmon as a minimum depth of 18 cm. On the Chena River in Interior Alaska, chum salmon redds in one study ranged in depth from 30 to 90 cm (Kogl 1965).

Methods

To address the first objective of what river features were associated with spawning habitat for chum salmon, a multiple scale approach was used. A habitat field study was conducted to establish baseline small-scale stream habitat characteristics and to map spawning locations. Subsequently an analysis of large-scale stream habitat features was conducted employing a time-series of remote sensing data. This hierarchical classification of small- and large-scale features has several advantages according to Frissell et al. (1986). Classification at higher levels lessens the number of variables at lower levels, provides for the integration of data from diverse sources and of differing resolutions, and allows selection at a level of resolution that most closely matches research objectives.

To address the second objective of providing a spawning habitat-based escapement goal, habitat models were developed under the assumption that a limited area of the river was capable of satisfying the spatial requirements and habitat preferences of chum salmon during the adult spawning life stage as specified in peer-reviewed journals. The model inputs were spawning location and frequency for each river strata, a range of spatial requirements for individual redd sites, and the area of stream bottom available as estimated through the habitat survey. Other assumptions incorporated in the model were that strata with a high density of spawning areas represent nodes of productivity that persist year to year and the number of spawning patches available can be estimated based on point-in-time observations of spawning patch distribution. This method was chosen because of its simplicity, low cost, and potential as a rapid assessment technique for determining spawning habitat and escapement goals.

The Tuluksak River was divided into six sections (Figure 3) based on gradient and sinuosity changes derived from a USGS topographical map (1:63,000) and numbered in ascending order from just upstream of the refuge boundary (Section 1) downstream to the USFWS counting weir (Section 6). Sinuosity is the ratio of channel length and valley center length and is used to characterize meandering streams (Figure 4). Fifty study sites were established across the six river sections including 44 that were determined randomly and 6 that were established in areas with observed spawning activity. Sites were randomized over all 6 sections by rolling a single 10-sided die and proceeding a fixed distance (in tenths of rkm) from our starting point in Section one. Every succeeding sampling site was the same fixed distance apart for the remainder of the section. When the next section boundary was crossed a new random fixed distance was generated. We recorded latitude and longitude at each site using a Global Positioning System (GPS) unit (Garmin Model 12XL). This information was recorded on data sheets and downloaded to All-Topo Brand mapping program. Each habitat site contained from 1 to 3 transects. Physical habitat attributes were measured including stream depth, width, and velocity. Sketch maps were made for each site depicting general channel shape and habitat type. Habitat types observed were grouped into three categories: riffles, runs, and pools (Bisson et al. 1982). Stream gradient was determined with a tripod-mounted Sokkia Brand 22X surveyor's level and a telescoping stadia rod.

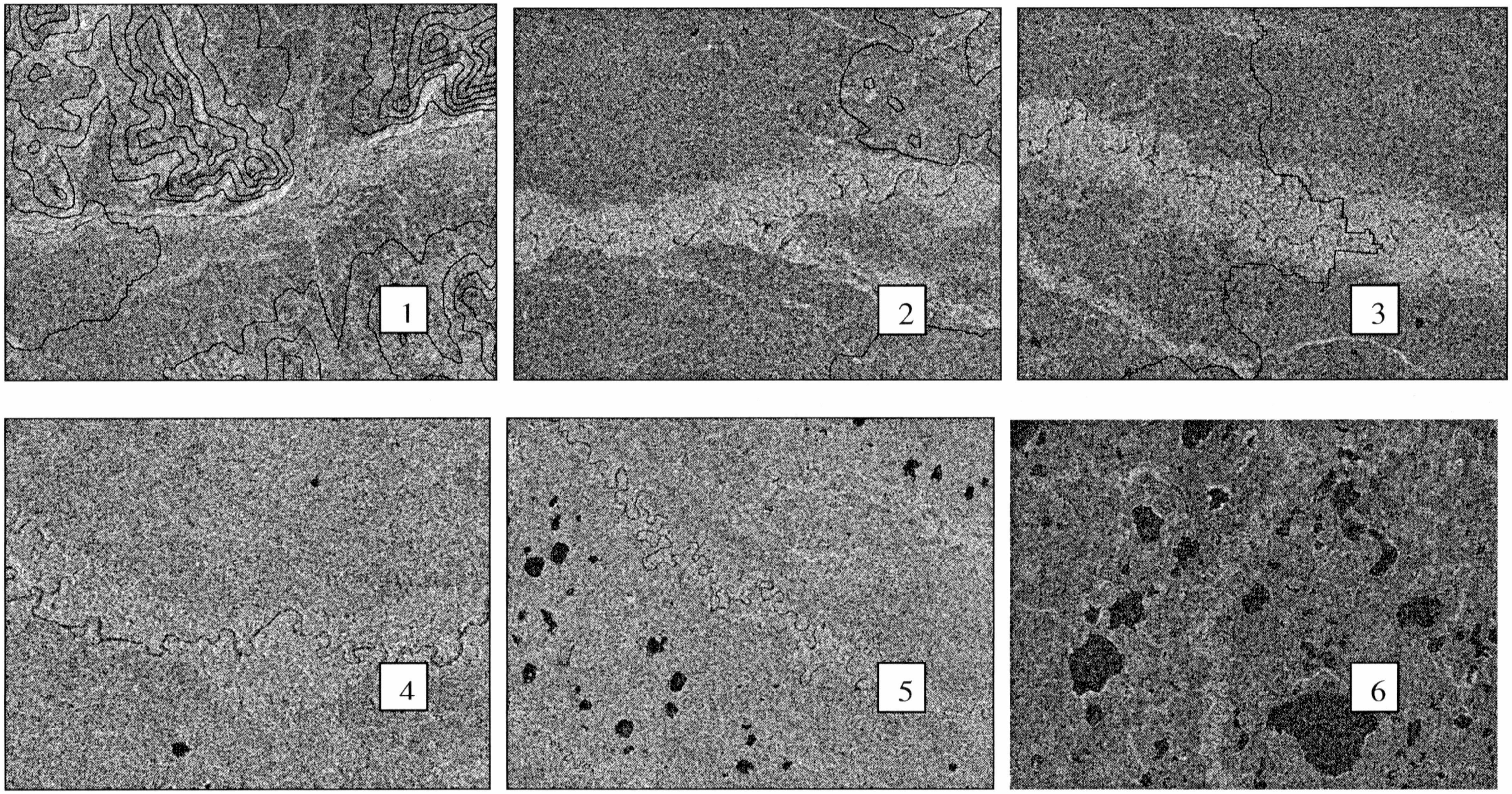

Figure 3 Tuluksak River SAR images of river sections. Sections were numbered upstream to downstream.

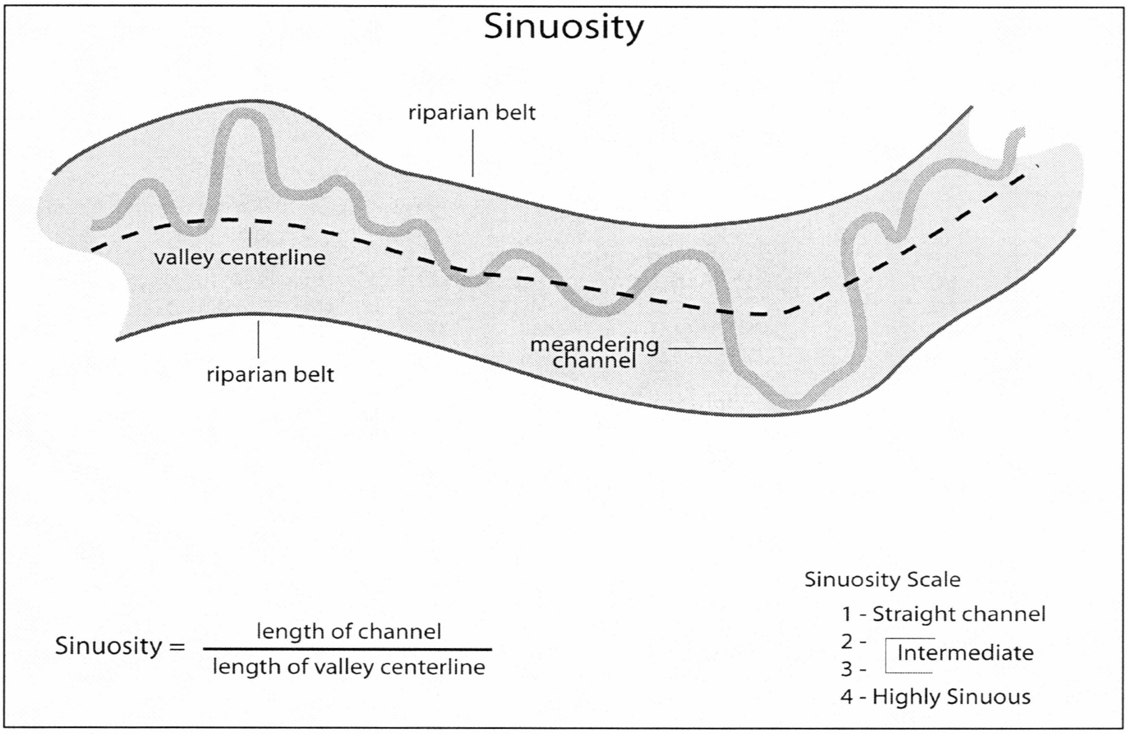

Figure 4. Diagram explaining the concept of sinuosity.

Visual estimates of substrate composition were made at 3 equidistant points across each transect. A 60-cm square grid was laid on the stream bottom, and percent composition within that area was estimated according to the Wentworth (1922) particle size scale. Wolman pebble counts were also carried out in 2003 (Wolman 1954). Transects were spaced at even distances to encompass spawning beds (if present) and overlapped the entire area for a short distance upstream and downstream. Inter-transect areas shallow enough to easily wade were selected for pebble counts and 100 particles were graded using the Wentworth scale of substrate size. Data from the two years were combined and standardized based on the particle size frequency in five categories modified from the Wentworth particle size scale (Wentworth 1922): 1) <2 mm, fine sediment, sand, silt or clay, 2) 2-32 mm, gravel, 3) >32-64 mm, coarse gravel, 4) >64-120 mm, small cobble, and 5) >120-256 mm, large cobble.

Direct observation was used to locate chum salmon spawning areas in the Tuluksak River in 2002 and 2003. The criteria used to designate spawning sites were the presence of at least 10 adult chum salmon in close proximity to well defined redds. Redds were identified by their clean appearance and "pit and tail spill" configuration (Kondou et al. 2001). When female chum salmon dig redds, they "actively remove periphyton from the rocks that make up the substrate that are clearly distinguishable from the surrounding undisturbed areas" (Visser et al. 2002). Width, depth, and length of 13 redds were measured to get an average redd area.

The Tuluksak River was examined using black and white aerial photography (June 1952 and August 1955; USGS), color infrared aerial (CIR) photography (August 1984), satellite imagery (LANDSAT7; NASA) and synthetic aperture radar (SAR; RADARSAT, copyright Canadian Space Agency). Black and white aerial photos were rectified and geo-referenced to the LANDSAT7 images and used as a benchmark to evaluate habitat change over time. Ground resolution (the smallest measurable detail on a remotely sensed image) was best using color CIR (~1.6 m/pixel) and black and white aerial photos (~0.84 m/pixel). Watershed characteristics of surficial geology, drainage boundaries, elevation contours, hydrology, and land cover were added to a Geographical Information System (GIS; ArcView version 9.0, ESRI) which integrated all data components. The Tuluksak River was digitized based on the LANDSAT 7 image layer. The resulting vector representing the river channel was segmented by stream wavelength

(Figure 5). Individual wavelength (λ) sinuosity was measured, then each wavelength combined into strata about 2 rkm in length (n=32). Some strata had several habitat sampling and spawning sites within their boundaries.

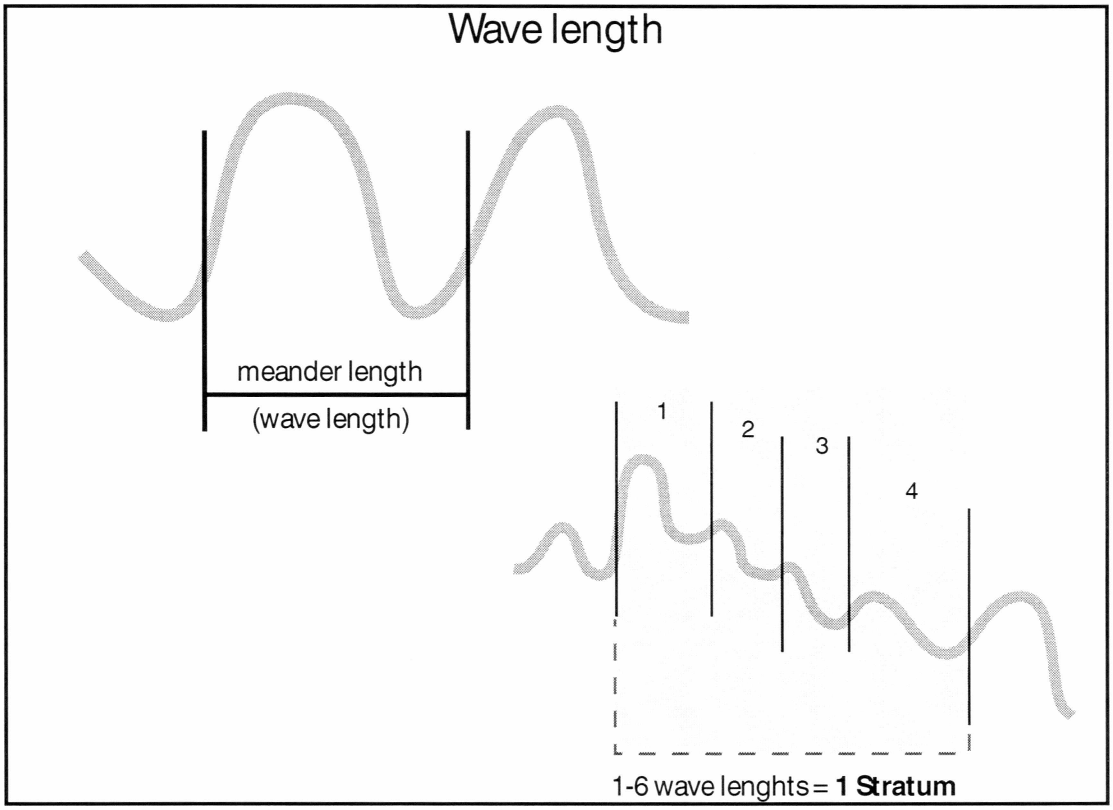

Figure 5. Diagram explaining stream wavelengths and strata concepts. Meander wavelengths (λ) were combined into strata approximately 2 km in length for the purpose of counting large-scale habitat features.

An ordinal scale was used to categorize the degree of channel change over time. River channel sample strata that remained stable over a 50-year time span as determined by comparing black and white aerial photos to SAR and LANDSAT7 images were assigned a rating of "1". Strata with an intermediate level of change were rated "2". Strata that underwent drastic changes (i.e. main channel abandonment, new channel formation etc.) over a 50-year period received a rating of "3".

A USGS digital elevation map was used to view the drainage pattern of the Tuluksak River (Figure 6). GIS was employed to quantify paleochannels, abandoned channels (old channel sections some of which still hold standing water and often act as spillways during high-water periods), oxbow lakes, thaw lakes (pingos), areas where the river was eroding into the tundra, as well as areas with heavy riparian cover.

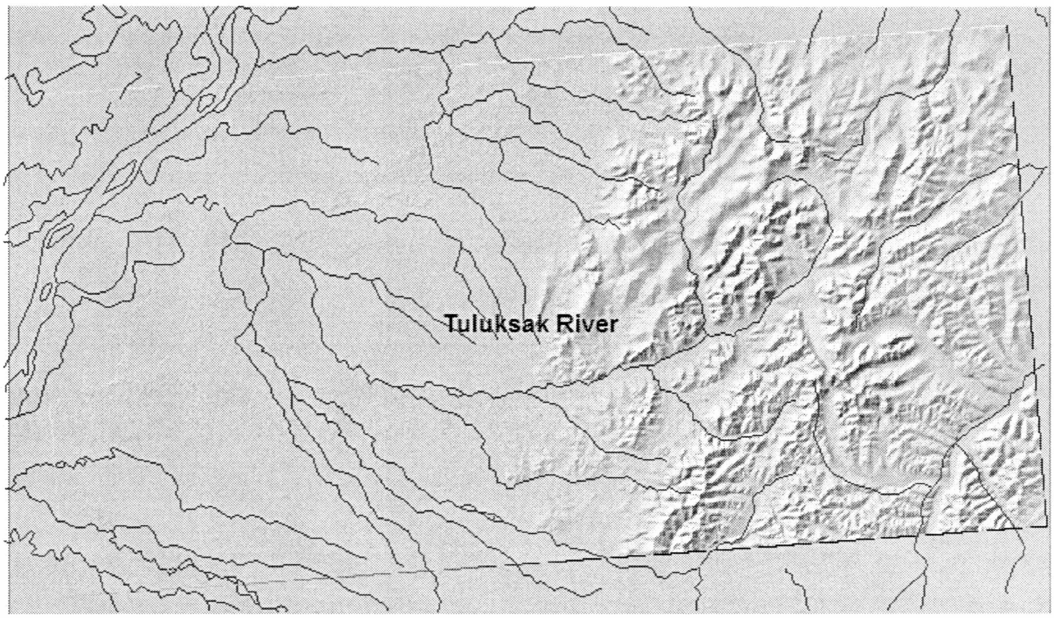

Figure 6. Tuluksak River digital elevation model.

Remote sensing-derived strata variables were sinuosity, number of channel intersections, number of gravel bars, number of islands, number of stream-tundra intersections, and the degree of channel change over time. Channel intersection (abbreviated "Ch.x") was a broad category that included any feature that intersected the main channel (tributary streams, sloughs, abandoned channels, paleochannels, etc.). Stream-tundra intersections were defined as locations where the stream was actively eroding tundra cut-banks. These areas typically lacked cover in the form of overhanging vegetation. Variations between the habitat variables of each strata and the number of spawning sites in each strata were examined through principal components analysis (PCA; Fitzpatrick et al. 1998). A forward, stepwise multiple linear regression analysis was employed to determine which large scale features were the best predictors of spawning habitat location.

The average redd area was 3.2 m^2 for chum salmon in the Tuluksak River. However spawning pairs of chum salmon have been observed to defend much larger areas from encroachment by other spawners. Past research on chum salmon suggested that the spatial requirement for a single redd is approximately 9.2m^2 (Burner 1951). An alternate means of estimating, spawning capacity can be obtained by dividing the total habitat area available by 4 times the average redd area (Burner 1951). These spatial requirement estimates, 3.2 m^2, 9.2 m^2 and 12.8 m^2 (4 times the averaged redd area for Tuluksak River chum salmon), translate to densities of 0.3125, 0.1086, and 0.0781 spawning pairs/m^2 respectively and were used to calculate spawning capacity. The total spawning habitat area of each river strata was determined by multiplying the total length of the section by one half of the average width for that section. The other half width was assumed to be outside the range of preferred habitat criteria depth, substrate, cover and flow conditions A range of habitat-based escapement goal estimates was then calculated using the 3 density estimates, an estimate of available spawning habitat and an adjustment for the incidence of spawning observed in each strata and each section. This observation-based model was modified by substituting the results of the regression model between channel intersections (the best predictor variable) and spawning sites for the factor that represented observed incidence of spawning. The result was 3 predictive models, one for the regression model and one each for the lower and upper bounds of a 95% confidence interval.

Results

Principal components analysis suggested a strong association between strata containing a high number of spawning areas (Table 1) and strata with high values for change over time, channel intersections, gravel bars, and islands (Figure 7). Stream strata containing a high number of spawning areas showed a negative association with stream strata that had high values for sinuosity and areas of tundra exposed to river erosion. Elevation and channel width were negatively correlated (-0.52) with spawning site frequency and location. The best predictor of the variation in spawning site density and location was channel intersection (Figure 8) and the second best was number of exposed gravel bars per strata. The regression equation between the variables representing location and number of spawning sites and location and number of channel intersections was used to form the predictive models (Table 2).

Table 1. Tuluksak River sections, strata, spawning sites and habitat notes.

Section	Strata	Number of spawning Sites	Habitat notes
1	2.1	0	Near mine tailings area, channel stable, semi-confined..
1	2.2	0	Tailings against hillslope, channel semi-confiend
1	2.3	0	Channel leaves tailings area, first major river bend
1	2.4	0	Channel flows straight along footslope, some braiding, island.
1	2.5	0	Straight, stable channel with islands and gravel deposits
1	2.6	0	Big river bend to the North around prominent footslope, island
2	2.7	2	spawning areas upstream of contour, stable since mid-1980s
2	2.8	0	Islands w/ heavy gravel deposits on leading edge and meander
2	2.9	1	Significant channel change and relocation of mainstem
2	3.0	1	Side channels and recent meander bends
3	3.1	2	Sloughs and overflow channels, tight meander bends
3	3.2	2	Main channel has migrated south and matured meander bends
3	3.3	3	River split into two major channels, islands and sloughs, grave
3	3.4	7	Large meander bends, sloughs
4	3.5	3	Abandoned channels
4	3.6	6	High rate of channel change, ch. x, islands and gravel bars
4	3.7	3	Channel intersections, gravel bars
4	3.8	3	Channel intersections and islands
5	3.9	0	Vegetation change over time is apparent
5	4.0	0	Highly stable meander bends
5	4.1	1	Many gravel bars and a tundra erosion site
5	4.2	0	Similar to previous strata
5	4.3	1	A notable increase in riparian vegetation
5	4.4	0	Highly stable meander bends
5	4.5	4	Channel intersections, gravel bars
6	4.6	0	Similar to previous strata
6	4.7	0	Channel stable over time
6	4.8	0	River-tundra intersection
6	4.9	0	River-tundra intersection, medium channel change over time
6	5.0	1	Oxbow lake adjacent to channel
6	5.1	0	Channel stable over time, sediment deposits
6	5.2	0	Similar to previous strata

The result of the observed spawning model was a maximum spawning capacity of 66,420 chum salmon at high spawner density (0.3125 spawners/m^2 or 3.2 m^2/spawning pair). Spawning capacity indicated by the observed spawning model at medium density (0.1086 spawners/m^2 or 9.2 m^2/spawning pair) was 23,080. The observed spawning model result at low density (0.0781 spawners/m^2 or 12.8 m^2/spawning pair) was 16,598. The results

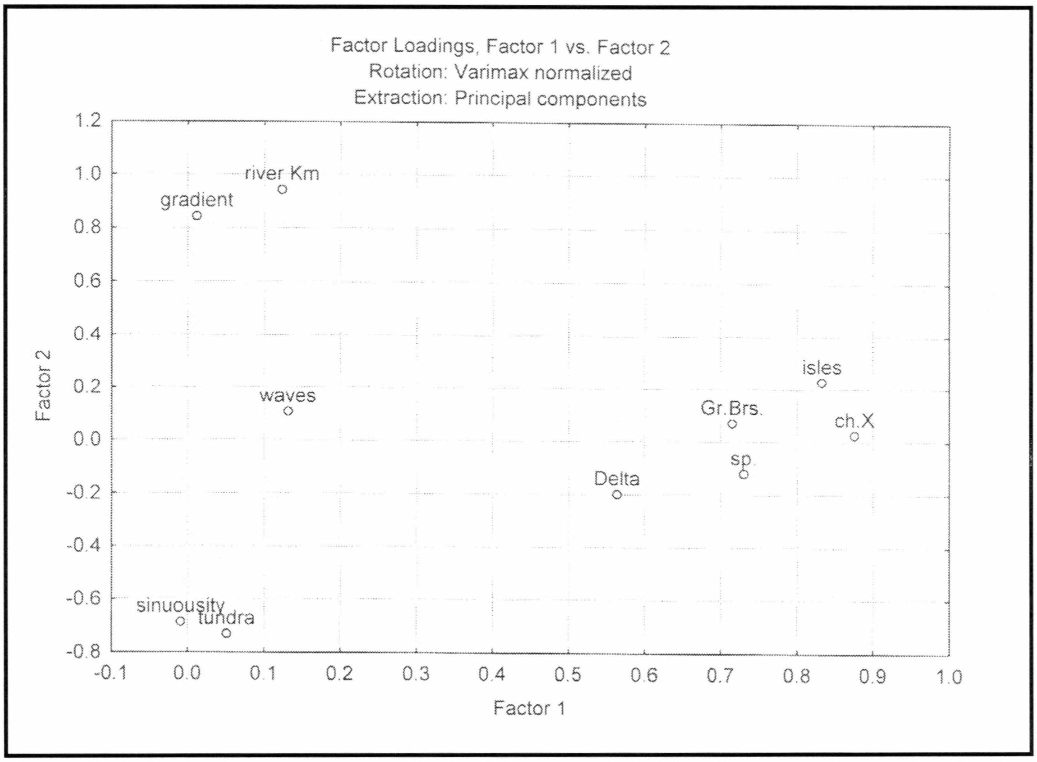

Figure 7. Principal components analysis of large-scale habitat features. Spawning site is abbreviated "sp.", gravel bars "Gr.Brs.", channel intersections "ch.x", degree of channel change over time "Delta", river-tundra intersection "tundra", and number of channel wavelength per strata "waves".

of the predicted spawning model (predictive model 1) were 16,255; 5,649; and 4,062 individual adult chum salmon for high, medium and low densities respectively (Table 3; Figure 2; Appendix A-1 to A-24). The lower bounds of the 95% confidence interval (predictive model 2) were 2,514, 874, and 632 and the upper bounds (predictive model 3) were 29,992, 10,426, and 7,496 individual adult chum salmon for high, medium, and low densities respectively (Table 3; Appendix A-1 to A-24).

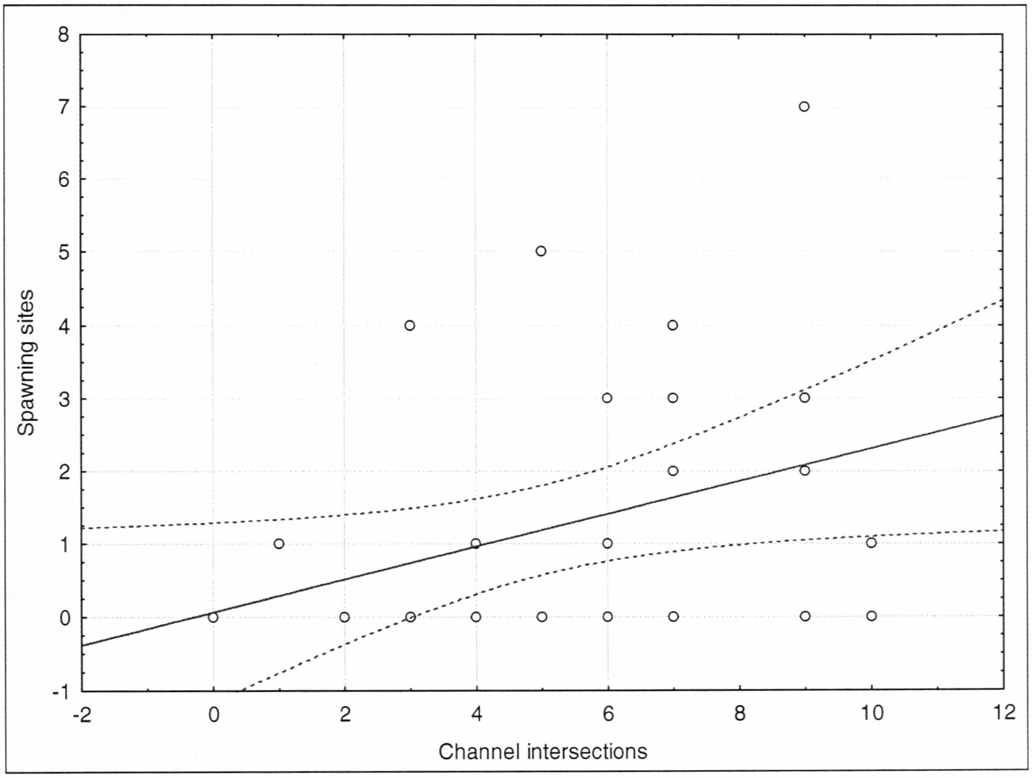

Figure 8. Regression plot of channel intersections and spawning sites.

Channel width ranged from 14 m (Section 3, site 3H) to 43.5 m (Section 1, site 206; Table 4). The average mean of all site transect widths was 24 m. In an upstream to downstream direction, channel widths narrowed in sections 1, 2, 3, and 4 but broadened again in Sections 5 and 6. Grouped by strata, the overall average channel width was 23.2 m. Channel widths were similar between spawning and non-spawning strata (Table 4).

Average channel depths ranged from 38 cm to 228.5 cm (Table 5). Average spawning strata depth was greater than average strata depth where no spawning was observed (Table 4). The average water depth of chum salmon redds was 65 cm (n=19).

Average current velocities ranged from 0.31 m/s to 1.45 m/s (Table5). Grouped by section, Section 1 had the highest average stream velocity (1.2 m/s) and Sections 4 and 6 had the lowest average stream velocity (0.59 m/s and 0.6 m/s respectively). There was no significant difference in average stream velocity between spawning strata and non-spawning strata (Table 4).

Table 2. Parameters of the predicted spawning habitat capacity model.

Model Parameter	Beta	Standard . error of Beta	B	Standard error of B	t(30)	p-level
Intercept			0.018382	0.599339	0.030671	0.97573
Ch.x	0.398358	0.167463	0.246324	0.103550	2.042	0.02393
n=32						

R= .39835813
R^2= .15868920
Adjusted R^2=.13064550
F(1,30)=5.6586
p<.02393
Std.Error of estimate: 1.7078

Table 3. Tuluksak River spawning habitat capacity model comparison. Observed spawning model and predictive spawning model results for three spawning densities. Predictive models 2 and 3 are the lower and upper bounds of a 95% confidence interval from the linear regression relationship between channel intersections and spawning sites.

Sections	**capacity 0.3125 pairs/m^2**	**capacity 0.1086 pairs/ m^2**	**capacity 0.0781pairs/ m^2**
	Observed spawning habitat model		
1	0	0	0
2	3,754	1,304	938
3	10,121	3,517	2,529
4	8,927	3,102	2,231
5	8,599	2,988	2,149
6	1,809	629	452
Total pairs	33,210	11,540	8,299
Total chum salmon	**66,420**	**23,080**	**16,598**
	Predictive model 1: $\hat{y}$ = 0.018382+0.246324 (ch.x)		
1	919	319	230
2	1,862	647	465
3	1,461	508	365
4	999	347	250
5	1,396	485	349
6	1,491	518	373
Total pairs	8,127	2,824	2,031
Total chum salmon	**16,255**	**5,649**	**4,062**
	Predictive model 2: $\hat{y}$ = 0.018382+0.034875 (ch.x)		
1	150	52	38
2	278	97	70
3	218	76	55
4	151	52	38
5	220	77	55
6	240	83	60
Total pairs	1,257	437	316
Total chum salmon	**2,514**	**874**	**632**
	Predictive model 3: $\hat{y}$ = 0.018382+0.4577731(ch.x)		
1	1,688	587	422
2	3,445	1,197	861
3	2,704	940	676
4	1,847	642	461
5	2,571	894	643
6	2,741	953	685
Total pairs	14,996	5,213	3,748
Total chum salmon	**29,992**	**10,426**	**7,496**

Percent stream slope ranged from 0.46 (Section 2) to 0.1 (Sections 5 and 6; Figure 9; Table 5). Section 1 had the overall highest average percent gradient (0.3) and Sections 5 and 6 had the lowest average percent gradient (0.1). Average stream slope was similar between spawning and non-spawning strata (Table 4).

Table 4. Tuluksak River strata habitat comparison. The sample size (n), sample mean ($\overline{x}$), and sample standard deviations (s) of strata where spawning was observed vs. non-spawning strata.

	Strata, observed spawning			Strata, no observed spawning		
	n	$\overline{x}$	*s*	*n*	$\overline{x}$	*s*
Channel x	15	6.333	2.870	17	3.824	2.580
Gravel bars.	15	10.0	4.053	17	6.118	3.586
Islands	15	2.467	1.642	17	1.353	1.455
Sinuosity	15	1.981	0.658	17	1.877	0.868
Ch. Δ	11	2.133	0.834	17	1.235	0.437
tundra	12	0.467	0.105	17	0.588	0.712
λ/strata	12	3.333	1.234	17	2.882	0.928
λ distance/strata	15	393.00	137.511	17	434.439	228.085
% Slope	15	0.241	0.105	12	0.227	0.148
Stream velocity	15	0.813	0.287	11	0.896	0.333
Width (m)	15	21.850	4.571	11	28.019	4.827
Depth (cm)	11	74.890	53.090	10	60.821	21.404
Width/depth ratio	12	18.207	6.373	10	25.964	11.483
Pref. substrate %	12	64.295	12.129	11	60.327	21.934

The stream bed substrate in the preferred spawning range for chum salmon (13-102 mm), varied from a low of 15% (Section 6) to a high of 83% (Sections 2 and 4; Table 5). On average the highest percentages of substrate in this preferred range were located in

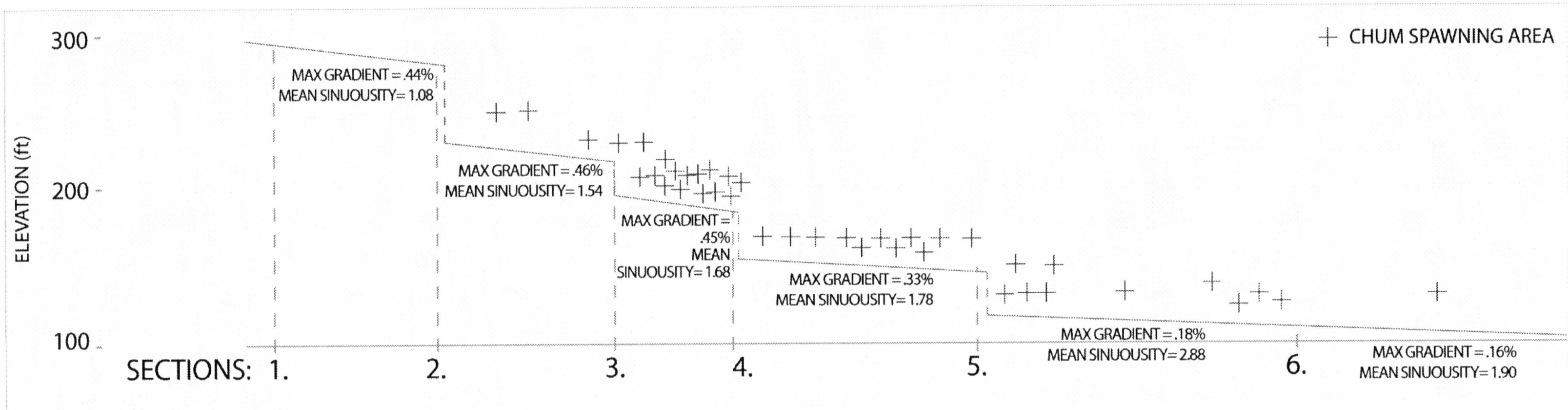

Figure 9. Elevation, gradient, sinuosity and spawning sites. This graph shows the approximate elevation of river sections above sea-level and the distribution of spawning sites in relation to maximum section gradient and mean section sinuosity

Table 5. Tuluksak River strata and small-scale habitat features.

Strata	River km (rkm)	Sampling sites	Approximate strata length (km)	Average Percent slope	Stream Velocity (m/s)	Average stream width (m)	Average depth (cm)	Width/depth ratio	Percent Substrate in preferred spawning range
2.1	127.7	-	2.2	0.45	-	-	-	-	-
2.2	125.5	-	2.1	-	-	-	-	-	-
2.3	123.4	1A,201	1.9	0.44	0.99	27	90	15	77
2.4	121.5	202-205	2.3	0.26	1.39	24.75	57	21.7	78
2.5	119.2	206,207,1B	2.08	0.26	1.23	27.6	45.4	30.32	73
2.6	117.1	208	1.84	0.46	1.26	28	53.45	26.16	-
2.7	115.26	209	2.5	-	1	28.2	56.6	24.9	78.25
2.8	112.74	2A,2B,210-212	2.54	0.15	1.03	20.16	106.96	9.42	71
2.9	110.2	2C,212- 214	2.26	0.37	0.94	24.6	55.95	21.96	83
3	107.94	2H,2D,3A,215-217	2.35	0.25	0.75	26.6	98.13	13.43	67
3.1	105.59	3B,3H,218-219	2.37	0.3	1.45	14.55	228.5	3.23	52
3.2	103.22	3c1,3C	1.77	0.42	1.01	24	112.5	10.6	-
3.3	101.45	3D,3E,220	2.47	0.19	0.89	19.9	54.4	18.09	67.2
3.4	98.98	3F, 3G,221	2.48	0.15	0.89	22.75	50.55	22.52	66.8
3.5	96.5	4A,4c2	2.13	0.31	0.54	16.7	43.1	19.41	66
3.6	94.37	4H	2.07	0.27	0.33	14.5	38	18.58	51
3.7	92.3	4c3,4D	1.9	0.1	0.73	25.6	49.8	25.6	39
3.8	90.4	4C,5H	1.89	0.19	0.58	21.5	55.25	19.36	68
3.9	88.51	-	2.06	-	-	-	-	-	-
4	86.45	5C	2.01	0.18	0.78	25.6	45.5	28.13	83
4.1	84.4	5E	2.52	0.1	0.65	23.3	55.9	20.8	68
4.2	81.88	5G	1.99	0.07	0.77	27	56	24.1	69
4.3	79.89	-	1.74	-	-	-	-	-	-
4.4	78.15	5I	1.64	0.11	0.68	30.6	59.8	25.71	53
4.5	76.51	-	2.24	-					-
4.6	74.27	6H	1.63	0.16	0.48	29.5	57	25.8	37.2
4.7	72.64	-	1.8	-	-	-	-	-	37.2
4.8	70.84	-	2	-	-	-	-	-	-
4.9	68.84	6C	2.12	0.07	0.31	28	-	-	15
5	66.7	-	2.27	-	-	-	-	-	-
5.1	64.43	6E	2.49	0.11	0.93	40	37.1	53.3	64.2
5.2	61.35	-	2.19	-	-	-	-	-	-

Sections 1 (75%) and 2 (75%). Of the remaining three sections in ascending order preferred range proportions were 53.2% (Section 4), 62% (Section 3), and 67.6% (Section 5). Spawning strata had slightly higher percentages of substrate in the preferred range (Table 4).

A total of 40 spawning areas were located (Table 1; Figure 10). 29 out of 40 (73%) were located in one 18-km stretch of the Tuluksak River that included all of Section 3 and Section 4. Of the remaining 11 spawning areas, 4 were in Section 2, 6 were in Section 5, and 1 was in Section 6. Chum salmon redds observed at these 40 spawning areas were grouped in clusters. The 13 chum salmon redds that were measured had an average redd area of 3.2m^2.

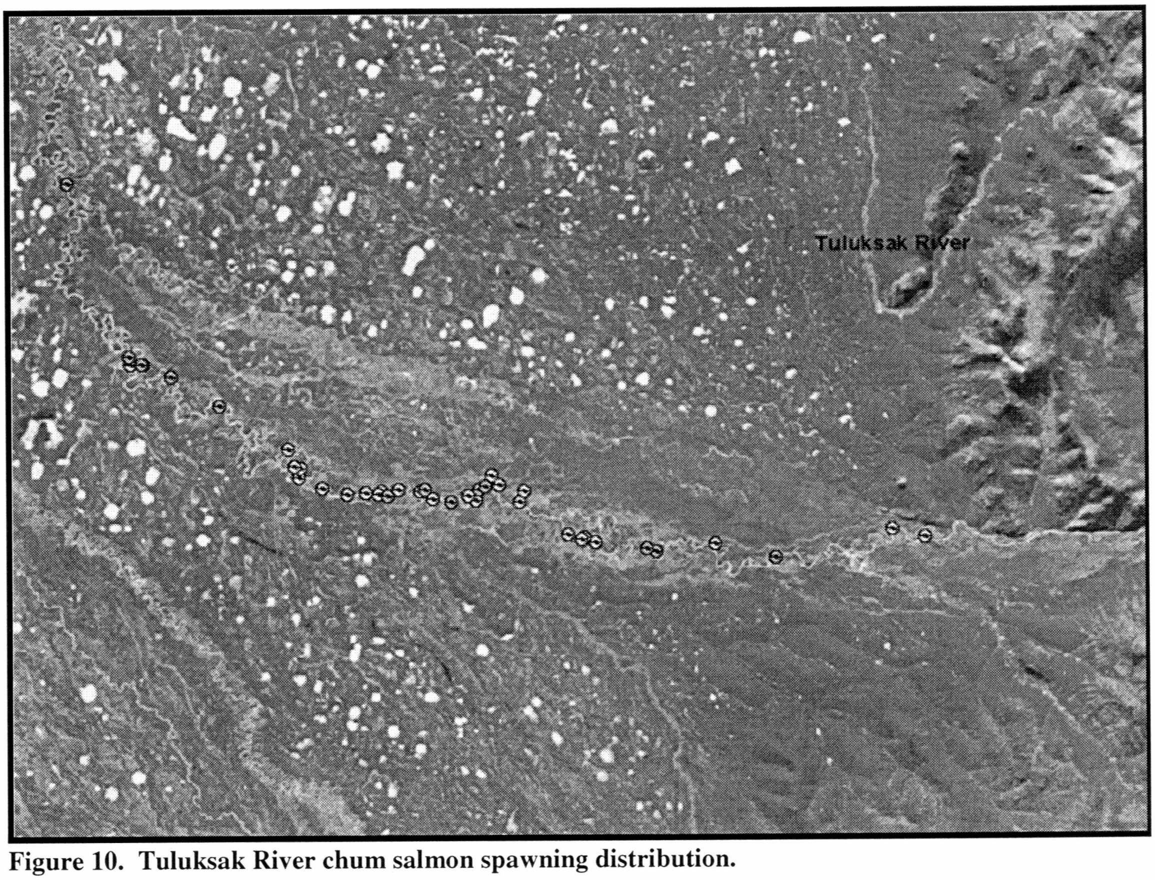

Figure 10. Tuluksak River chum salmon spawning distribution.

Strata sinuosity ranged from 1.02 (stratum 2.5) to 4.0 (stratum 4.6; Table 6; Figure 11). Strata sinuosity averaged by Section ranged from 1.1 (Section 1) to 2.7 (Section 5) and spawning and non-spawning strata were similar (Table 4). However, spawning sites were negatively associated with high sinuosity strata (Figure 7).

High scores for channel change over time were associated with strata with above average numbers of spawning sites (Figure 7) and channel change averages for spawning strata were substantially higher than non-spawning strata (Table 4).

Channel intersections per stratum ranged from 0.0 to 10.0 (Table 6). The range of the number of channel intersections averaged by section was 2.8 (Section 1) to 8.3 (Section 3). The channel intersection averages for the remaining sections in ascending order were 3.4 (Section 6), 3.7 (Section 5), 6.8 (Section 4) and 8.0 (Section 2). The number of channel intersection in spawning strata was nearly double the number identified in non-spawning strata (Table 4).

The number of gravel bars per strata ranged from 0.0 to 15.0 (Table 6). The number of gravel bars averaged by section ranged from 4.2 (Section 1) to 13.5 (Section 2). The number of gravel bars averaged by section for the remaining sections in ascending order was 6.3 (Section 5), 6.9 (Section 6), 7.5 (Section 4) and 13.3 (Section 3). The average number of gravel bars in spawning strata was substantially higher than the number in non-spawning strata (Table 4).

Table 6. Tuluksak River strata and large-scale habitat features.

	Large scale habitat features (detected through remote sensing)								
Strata	Strata length (km)	λ/strata	λ Average distance (m)	Sinuosity	Channel intersections	Gravel bars	Islands	Degree of channel change	Tundra
2.1	2.2	2	977.45	1.13	0	0	0	1	0
2.2	2.1	4	489.8	1.06	0	0	0	1	0
2.3	1.9	3	549.67	1.17	0	3	0	1	0
2.4	2.3	3	735.66	1.05	6	4	1	1	0
2.5	2.08	3	668.05	1.02	7	10	4	1	0
2.6	1.84	2	714.01	1.26	4	8	4	1	0
2.7	2.5	2	611.1	2.12	9	11	5	1	0
2.8	2.54	3	494.7	1.69	7	14	4	1	0
2.9	2.26	5	375.8	1.22	10	14	4	2	0
3.0	2.35	3	523.2	1.51	6	15	1	2	1
3.1	2.37	6	242.22	1.77	7	12	5	3	0
3.2	1.77	4	333.82	1.36	10	14	3	3	1
3.3	2.47	3	486.17	1.79	7	12	2	2	0
3.4	2.48	2	604.92	2.04	9	15	5	2	1
3.5	2.13	4	337.88	1.61	7	10	2	3	0
3.6	2.07	4	249.17	2.14	5	12	2	3	0
3.7	1.9	4	256.86	1.68	6	6	1	3	0
3.8	1.89	2	601.03	1.67	9	2	3	3	2
3.9	2.06	2	289.45	3.10	9	9	2	2	1
4.0	2.01	3	195.99	3.16	3	5	1	1	0
4.1	2.52	3	344.57	2.64	4	8	2	1	1
4.2	1.99	4	292.34	1.69	4	8	1	2	1
4.3	1.74	2	261.24	3.44	2	5	1	1	0
4.4	1.64	1	253.46	1.36	2	4	0	1	1
4.5	2.24	2	271.2	3.25	3	5	0	1	1
4.6	1.63	2	137.15	4.0	5	6	2	2	1
4.7	1.8	2	284.52	2.52	4	5	0	1	1
4.8	2.0	4	291.94	1.88	5	9	2	1	2
4.9	2.12	4	316.32	1.73	4	8	1	2	2
5.0	2.27	4	395.82	1.48	1	9	1	2	0
5.1	2.49	4	308.3	2.21	2	7	0	1	1
5.2	2.19	3	386.66	1.87	3	4	1	1	0

The number of islands per stratum ranged from 0 to 5 (Table 6). The number of islands per stratum averaged by section ranged from 1.0 (Sections 5 and 6) to 3.8 (Section 3). The number of islands per stratum averaged by section for the remaining sections in ascending order was 1.5 (Section 1), 2.0 (Section 4) and 3.5 (Section 2). Spawning strata had nearly twice the number of islands as non-spawning strata (Table 4).

The number of river-tundra intersections per stratum ranged from 0 (including at least 1 stratum from each section) to 2 (Sections 4 and 6; Table 6). The number of river-tundra intersections per stratum averaged by river section ranged from 0 (Section 1) to 1.0 (Section 6). The number of river-tundra intersections per stratum averaged by section for the remaining sections in ascending order was 0.3 (Section 2), 0.5 (Sections 3 and 4) and 0.7 (Section 5). Although the difference in average number of river-tundra intersections between spawning and non-spawning strata was slight, no spawning was observed adjacent to these areas.

Discussion

My results demonstrate that large-scale stream habitat characteristics which can be determined remotely combined with small-scale habitat characteristics which must be sampled *in situ*, can provide a basis for predicting the types of spawning habitat that are likely to be used by chum salmon in alluvial streams of this size. Predictions of spawning habitat availability can aid in the estimation of spawning habitat capacity e.g. habitat-based escapement goals, particularly in remote systems that are not easily accessed by conventional means. Three important points illustrated by the PCA support this assertion: 1) stream strata with high spawning use were associated with stream strata that had undergone a high amount of change over time, had a high number of channel intersections, islands and gravel bars; 2) strata with high sinuosity and strata with a high number of active tundra erosion sites were negatively associated with strata that has a high number of spawning areas and, 3) high values for gradient were associated with sites furthest upstream (highest elevation) and negatively associated with stream strata that had a high number of spawning sites. These observations reinforce the idea that river morphology determines the quantity and quality of in-stream habitat for living organisms (Gilvear et al. 1995). River channel morphology presents a network of interrelated factors affecting chum salmon spawning habitat and is the framework within which a discussion of these factors must take place.

Channel morphology and spawning habitat for salmon are related to the sources and locations of upwelling areas. For example, in a study on bull trout (*Salvelinus confluentus*) spawning, spawning site density increased in alluvial valley segments bounded by geomorphic knickpoints (Baxter and Hauer 2000). These areas had complex patterns of hyporheic exchange and extensive upwelling, strong localized down welling and high intragravel flow rate. The channel intersection category represented abandoned channels, tributaries, side channels, and sloughs associated with the Tuluksak River. It was a substitute for the direct measurement of upwelling which can be logistically difficult, costly and time consuming in remote locations. Junctions between the main channel and side channel features were likely to have increased the complexity of subsurface water flow and storage and have been called preferential flow pathways (PFP; Poole et al. 2002; Stanford and Ward 1993). They sometimes are formed when channel avulsion causes the river to abandon portions of the river bed during floods (Poole et al. 2002). Other features directly correlated with channel intersections may also have an impact on special flow conditions (i.e. upwelling/downwelling zones). Islands are important geomorphic features (Geist and Dauble 1998) that divert stream flow and influence the hydrology of the immediate surrounding channel, increase habitat complexity and are key elements of ecosystem functioning (Gurnell and Petts 2002). A general increase in habitat complexity may explain the co-occurrence of high numbers of islands and spawning areas (Stratum 3.5, in Section 3). In addition to islands other obstructions such as log jams, root wads and beaver dams may have an impact on localized hydrologic function (such as upwelling or down welling).

The spawning habitat for chum salmon in the Tuluksak River was associated with intermediate river channel sinuosity. Main-stem channel spawning is located in meandering channel configurations (S. Maclean, Alaska Department of Natural Resources [AKDNR], personal communication). Surface water tends to percolate down through the loose alluvium of meander bends along hydraulic gradients to later up-well at a downstream location. As the stream gradient decreased further, sinuosity increased to a high level and the river lost the power to transport fine sediment, except in high flow or flood conditions, so sand, silt and clay particles dropped out of suspension. Some evidence for a habitat-channel morphological link has been reported by others for various salmonids (Fukishima 2001). Sakhalin taimen (*Hucho perryi*) purportedly chose spawning spots below reaches with higher than average sinuosity (Fukishima 2001). Stream meandering is caused by low gradient and influenced by discharge and bed load, e.g. the sediment transported by a stream (Easterbrook 1993). Sinuosity may have an influence on pool-riffle frequency, bank erosion and woody debris input. On the Tuluksak River 75% of spawning areas were located in strata with intermediate sinuosity (1.5-2.5), 10% were in low sinuosity strata (<1.5) and, 15% in high sinuosity strata (2.5-3.5).

Spawning sites are located in secondary channels (commonly the lower end) where short distances (approx. < 200 m) are found between primary and secondary channels (S. Maclean, AKDNR, personal communication,). Main-stem channel spawning is located in meandering channel configurations where relatively short distances are found between the upstream and downstream channels (spawning is found along the downstream cut bank). This also includes the lower end of a gravel bar (Leman 1993; S. Maclean, AKDNR, personal communication). Spawning generally occurs off the trailing edge of sand/gravel bars against cut banks and in side sloughs (C. Burkey, ADF&G Biologist, personal communication). Riffle-pool sequences are commonly formed at channel bends in low-gradient alluvial streams (Bisson et al. 1982). On the Tuluksak River many spawning sites were sheltered by cover in the form of trailing limbs and overhanging vegetation (personal observation). Riparian vegetation is important to chum salmon spawning habitat by providing cover and a source of large woody debris (LWD) to the river channel. Cover can be in the form of overhanging vegetation, undercut banks, submerged objects, woody debris or deep water

The strata within Sections 3 and 4 changed drastically over the 52 year time series depicted by the remotely sensed images. The river's flow constantly eroded some portions of the channel while filling in others. This is called cut and fill alluviation (Lorang et al. 2005). Heavy spawning use in these areas implied that they contained areas of active upwelling and freshly exposed gravel patches. Stream gradient is a major factor which influences accelerated channel change and stream habitat for salmon and other fish. In addition, it is the underlying attribute driving substrate particle size, distribution of habitat types and hydrologic characteristics. Gradient has been used to predict fish distribution (Argent 2003), and changes in gradient have been associated with variations in trout abundance (Torgersen et al. 2004). Areas of abrupt stream gradient change can spur erosion at knickpoints. Geomorphic knickpoints are areas of channel change that appear where the river encounters a durable obstruction or constriction, and which influence river hydraulics both up and downstream. These spatially discrete strike points control the strength of upwelling and down welling and are gradient dependent. On a low gradient stream such as the Tuluksak River, points of gradient change are particularly influential and two geomorphic knickpoints almost completely bracket the longitudinal extent of spawning areas. One is located at the boundary between Section 1 and Section 2 where the river curves away from the foot slopes of the Kilbuk Mountains and a second is located in Section 5 just upstream of a braided section in which the main channel is constricted by a log jam. The accumulation and transport of LWD has geomorphologic effects such as increasing channel stability. LWD dams provide sites for channel avulsion and the initiation of secondary channels that become stabilized into a hierarchy of channels in smaller streams that support flow at different stages throughout the year (Gurnell and Petts 2002). Channel width is influenced by wood debris

(Montgomery et al. 2003) which can form stable in-stream structures affecting alluvial morphology (Abbe and Montgomery 2003). Stream widths narrowed in these heavily used sections, in part due to the accumulation of LWD and braiding of the main stem of the Tuluksak River into separate channels.

In Section 5 and 6 as the sinuosity of the river channel increased, the Tuluksak River banks were subject to lateral erosion which undercut tussock tundra and permafrost layers. At active tundra erosion sites, river banks were not well-vegetated and provided little cover for fish. Mats of eroded tundra were found to have fallen into the stream where they were buried by coarse sediment. The decomposition of these turf chunks may contribute to poor spawning conditions. There was no observed spawning use by chum salmon in these areas. The thawing of discontinuous permafrost is becoming widespread and extensive areas of thermokarst terrain are being created as a result of climatic change (Ostercamp 2003). North facing slopes in the Kilbuck Mountains remain frozen year round. South facing slopes are subject to freezing and thawing. This affects the patterns of recharges in the mountain aquifers and discharge as groundwater. Global temperatures are forecasted to rise by 3 ^{o}C over the next one hundred years (Chatters et al. 1991) and groundwater temperatures are expected to follow (Meisner et al. 1988). At high latitudes permafrost may decrease (Meisner et al. 1988). This is already occurring in some areas (Ostercamp 2003). Research is needed to gauge the impact of these changes on chum salmon habitat.

Chum salmon are reported to spawn over a wider range of substrate than other salmon (Geist et al. 2002) and areas of slower water (Kogl 1965; Smith 1973) in comparison with other salmon. On a microhabitat system level, salmon have been reported to use hydraulically sheltered and stable gravel patches (Montgomery et al. 1999). Substrate influences permeability, porosity, flow of intragravel water, dissolved oxygen concentration, concentration of waste metabolites such as carbon dioxide and ammonia, the armoredness or resistance to abrasion of the substrate surface, and the degree of embeddedness of larger sized particles in the substrate surface (Hale and McMahon 1981). Chum salmon spawning areas typically have well–sorted cobble and gravel substrate and floodplains that mitigate flood scour (Baxter and Hauer 2000). This causes suitably-sized spawning substrates to be limited and patchy in confined segments. The preferred substrate range for spawning chum salmon is 13-102 mm, according to Smith (1973), which is medium-sized gravel up to medium-sized cobble on the Wentworth particle size scale (Wentworth 1922). Gravel patches containing a particulate composition that is 60% within the range of 10-100 mm and less than 10% fine sediment should be considered excellent spawning habitat (Hale and McMahon 1981). The section with the highest spawning use (Section 4) was only 56% inside preferred spawning range suggesting that other habitat conditions were favorable for spawning and of greater importance.

Migrating chum employ a combination of sensory cues and behavioral patterns to make spawning site selections (Groot and Margolis 1991). While sensitive to minute temperature and chemical gradients they may also be responding to the presence of other salmon, redd-building or disturbed gravel indicating previous redd excavation. Competition for spawning sites occurs between chum salmon females and Chinook, pink, silver and occasionally sockeye salmon. Competition is avoided by a diffusion of the run timing for chum and mitigated in part by interspecific habitat segregation. The concept of the habitat model requires each spawning pair (equal to 1 female and 1 male) to select and defend a habitat patch from habitat that is potentially available. A patch is defined as the actual redd area plus any area surrounding the redd area that is actively defended, at least initially, by the female. This patch may be later overlapped or completely superimposed by another patch. Occasionally pink salmon and chum salmon migrate into small stream systems and completely overrun the habitat; redd superimposition often results in egg loss and poor incubation conditions (Bjornn and Reiser 1991). With 5 species of salmon spawning in the Tuluksak River some redd superimposition undoubtedly occurs, but overcrowded conditions were not observed. In fact, as our habitat-based capacity estimates suggest, the Tuluksak River was probably "under-seeded" with spawning chum salmon. An unknown portion of the Tuluksak River's annual run is harvested in the mixed-stock ocean and freshwater fisheries of the Lower Kuskokwim River and Kuskokwim Bay. The combined fishing pressure for of the commercial and subsistence fisheries is less than in previous decades. A chum salmon escapement of the size estimated by the observed spawning model at maximum density (66,420) is unlikely but not impossible. A very large return of Tuluksak River chum salmon (>30,000) was experienced in 2005. Perhaps a threshold exists between 35,000 and 65,000 (approximately) that triggers the aforementioned competition and redd superimposition to an extant that impacts production. The precise escapement level that would activate such a negative feedback mechanism is speculative. In addition the optimal escapement level to impart maximum ecosystem nutrients is also speculative and likely to be quite different from the spawning capacity.

Healthy salmon stocks require good fisheries management that sets effective and realistic catch and spawning recruitment goals. Traditionally, biological escapement goals are set using stock-recruit models (Ricker 1954). Today these models are known as the Ricker curves. Their domed-shape implies ecological feedback mechanisms that predict increased stock recruits at spawner levels below system carrying capacity, and juvenile production decreases as adult returns exceed system carrying capacity (National Research Council 1996). In other words as the number of individuals that spawn within a population increases, a linear increase in recruits to the population follows, up and to a point where system carrying capacity is reached. At that point the density of spawners is so high that a negative feedback reaction is triggered and the number of recruits to the population plummets. Resources, be it space for spawning sites, nutrients or food are over-allocated and the population, in theory, suffers. Due, in part, to their broad applicability, spawner-recruit models have become ensconced as the dominant paradigm in modern fisheries management. Blind adherence to stock-recruit type management in the face of uncertainty bolsters the arguments of some who have questioned the ability of fisheries agencies to learn from experience (Hilborn 1992). In establishing escapement goals we decide how much is “optimal”. Management should be based on the best available scientific data, as mandated by State of Alaska’s Policy for the management of sustainable salmon fisheries (5 AAC 39.222), routinely updated and subject to peer review. I recommend future research that targets the use of spawning habitats by chum salmon in other Kuskokwim River tributaries. By comparing the spawning areas of the Tuluksak River with the spawning areas of other rivers we can begin to develop habitat-based escapement goals that optimize the use of the spawning habitat that is available. Spawning habitats that are fully utilized may restore spawning runs that are capable of replenishing both the population and the ecosystem. In general this method may become a valuable tool for salmon management. It is recognized that while the numbers presented provide a credible example of an assessment process, they do not provide a definitive answer. Instead, they represent a first attempt at applying a system-specific, habitat framework to the estimation of spawning habitat capacity. Further testing on other streams of similar type and dimension is recommended.

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Table A-1. Spawning habitat capacity of Section 1, observed habitat model. The model is based on habitat characteristics and observations (incidence of spawning), at 3 different density levels. The total spawning capacity for all Section 1 strata at each density is listed in bold type as pairs of adult salmon (assuming a 1:1 sex ratio).

Section 1							
Strata	Strata length (m)	Spawning density/m^2	50% of average width(m)	Incidence of spawning	Spawning area (m^2)	Estimated spawner capacity	Adjusted spawning capacity
2.1	2,230.54	0.3125	13	0	28,997.02	9,062	0
2.2	2,087.63	0.3125	13	0	27,139.19	8,481	0
2.3	1,906.86	0.3125	13	0	24,789.18	7,747	0
2.4	2,304.44	0.3125	13	0	29,957.72	9,362	0
2.5	2,089.68	0.3125	13	0	27,165.84	8,489	0
2.6	1,840.65	0.3125	13	0	23,928.45	7,478	0
2.1	2,230.54	0.1086	13	0	28,997.02	3,149	0
2.2	2,087.63	0.1086	13	0	27,139.19	2,947	0
2.3	1,906.86	0.1086	13	0	24,789.18	2,692	0
2.4	2,304.44	0.1086	13	0	29,957.72	3,253	0
2.5	2,089.68	0.1086	13	0	27,165.84	2,950	0
2.6	1,840.65	0.1086	13	0	23,928.45	2,599	0
2.1	2,230.54	0.0781	13	0	28,997.02	2,265	0
2.2	2,087.63	0.0781	13	0	27,139.19	2,120	0
2.3	1,906.86	0.0781	13	0	24,789.18	1,936	0
2.4	2,304.44	0.0781	13	0	29,957.72	2,340	0
2.5	2,089.68	0.0781	13	0	27,165.84	2,122	0
2.6	1,840.65	0.0781	13	0	23,928.45	1,869	0

Table A-2. Spawning habitat capacity of Section 1, predictive model 1. This model is based on the results of multiple regression analysis and utilizes the density of channel intersections to predict the number of spawning sites/strata. The adjusted spawning capacity is made up of pairs of adult chum salmon with the assumption of a 1:1 sex ratio. Total spawning pairs of all Section 2 strata, at each density are listed in bold type.

Section 1							
Strata	**Strata length (m)**	**Spawning density/m^2**	**50% of average width(m)**	**Prediction of spawning**	**Spawning area (m^2)**	**Estimated spawner capacity**	**Adjusted spawning capacity**
2.1	2,230.54	0.3125	13	0.000459549	28,997.02	9,062	4
2.2	2,087.63	0.3125	13	0.000459549	27,139.19	8,481	4
2.3	1,906.86	0.3125	13	0.000459549	24,789.18	7,747	4
2.4	2,304.44	0.3125	13	0.03740809	29,957.72	9,362	350
2.5	2,089.68	0.3125	13	0.04356618	27,165.84	8,489	370
2.6	1,840.65	0.3125	13	0.02509191	23,928.45	7,478	188
							919
2.1	2,230.54	0.1086	13	0.000459549	28,997.02	3,149	1
2.2	2,087.63	0.1086	13	0.000459549	27,139.19	2,947	1
2.3	1,906.86	0.1086	13	0.000459549	24,789.18	2,692	1
2.4	2,304.44	0.1086	13	0.03740809	29,957.72	3,253	122
2.5	2,089.68	0.1086	13	0.04356618	27,165.84	2,950	129
2.6	1,840.65	0.1086	13	0.02509191	23,928.45	2,599	65
							319
2.1	2,230.54	0.0781	13	0.000459549	28,997.02	2,265	1
2.2	2,087.63	0.0781	13	0.000459549	27,139.19	2,120	1
2.3	1,906.86	0.0781	13	0.000459549	24,789.18	1,936	1
2.4	2,304.44	0.0781	13	0.03740809	29,957.72	2,340	88
2.5	2,089.68	0.0781	13	0.04356618	27,165.84	2,122	92
2.6	1,840.65	0.0781	13	0.02509191	23,928.45	1,869	47
							230

Table A-3. Spawning habitat capacity of Section 1, predictive model 2. Predictive model 2 is the lower bounds of a 95% confidence interval for the results of the regression equation between observed channel intersections and spawning site location. The model represents a remote sensing index that can be used to predict spawning capacity. Adjusted spawning capacity estimate is for pairs of adult salmon, assuming a 1:1 sex ratio. The totals of all Section 1 strata estimates at each density are listed in bold type.

Section 1

Strata	Strata length (m)	Spawning density/m^2	50% of average width(m)	Prediction of spawning	Spawning area (m^2)	Estimated spawner capacity	Adjusted spawning capacity
2.1	2,230.54	0.3125	13	0.00045955	28,997.02	9,062	4
2.2	2,087.63	0.3125	13	0.00045955	27,139.19	8,481	4
2.3	1,906.86	0.3125	13	0.00045955	24,789.18	7,747	4
2.4	2,304.44	0.3125	13	0.0056908	29,957.72	9,362	53
2.5	2,089.68	0.3125	13	0.006562675	27,165.84	8,489	56
2.6	1,840.65	0.3125	13	0.00394705	23,928.45	7,478	30
							150
2.1	2,230.54	0.1086	13	0.00045955	28,997.02	3,149	1
2.2	2,087.63	0.1086	13	0.00045955	27,139.19	2,947	1
2.3	1,906.86	0.1086	13	0.00045955	24,789.18	2,692	1
2.4	2,304.44	0.1086	13	0.0056908	29,957.72	3,253	19
2.5	2,089.68	0.1086	13	0.006562675	27,165.84	2,950	19
2.6	1,840.65	0.1086	13	0.00394705	23,928.45	2,599	10
							52
2.1	2,230.54	0.0781	13	0.00045955	28,997.02	2,265	1
2.2	2,087.63	0.0781	13	0.00045955	27,139.19	2,120	1
2.3	1,906.86	0.0781	13	0.00045955	24,789.18	1,936	1
2.4	2,304.44	0.0781	13	0.0056908	29,957.72	2,340	13
2.5	2,089.68	0.0781	13	0.006562675	27,165.84	2,122	14
2.6	1,840.65	0.0781	13	0.00394705	23,928.45	1,869	7
							38

Table A-4. Spawning habitat capacity of Section 1, predictive model 3.. Predictive model 3 is the upper bounds of a 95% confidence interval for the results of the regression equation between observed channel intersections and spawning site location. The model represents a remote sensing index that can be used to predict spawning capacity. Adjusted spawning capacity estimate is for pairs of adult salmon, assuming a 1:1 sex ratio. The totals of all Section 1 strata estimates at each density are listed in bold type.

Section 1							
Strata	Strata length (m)	Spawning density/m^2	50% of average width(m)	Prediction of spawning	Spawning area (m^2)	Estimated spawner capacity	Adjusted spawning capacity
2.1	2,230.54	0.3125	13	0.00045955	28,997.02	9,062	4
2.2	2,087.63	0.3125	13	0.00045955	27,139.19	8,481	4
2.3	1,906.86	0.3125	13	0.00045955	24,789.18	7,747	4
2.4	2,304.44	0.3125	13	0.0691255	29,957.72	9,362	647
2.5	2,089.68	0.3125	13	0.080569825	27,165.84	8,489	684
2.6	1,840.65	0.3125	13	0.04623685	23,928.45	7,478	346
							1,688
2.1	2,230.54	0.1086	13	0.00045955	28,997.02	3,149	1
2.2	2,087.63	0.1086	13	0.00045955	27,139.19	2,947	1
2.3	1,906.86	0.1086	13	0.00045955	24,789.18	2,692	1
2.4	2,304.44	0.1086	13	0.0691255	29,957.72	3,253	225
2.5	2,089.68	0.1086	13	0.080569825	27,165.84	2,950	238
2.6	1,840.65	0.1086	13	0.04623685	23,928.45	2,599	120
							587
2.1	2,230.54	0.0781	13	0.00045955	28,997.02	2,265	1
2.2	2,087.63	0.0781	13	0.00045955	27,139.19	2,120	1
2.3	1,906.86	0.0781	13	0.00045955	24,789.18	1,936	1
2.4	2,304.44	0.0781	13	0.0691255	29,957.72	2,340	162
2.5	2,089.68	0.0781	13	0.080569825	27,165.84	2,122	171
2.6	1,840.65	0.0781	13	0.04623685	23,928.45	1,869	86
							422

Table A-5. Spawning habitat capacity of Section 2, observed habitat model. Estimated spawning capacity of Section 2 was based on habitat characteristics and observations (incidence of spawning), at 3 different density levels. The total spawning capacity for all Section 2 strata at each density is listed in bold type as pairs of adult salmon (assuming a 1:1 sex ratio).

Section 2							
Strata	**Strata length (m)**	**Spawning density/m^2**	**50% of average width(m)**	**Incidence of spawning**	**Spawning area (m^2)**	**Estimated spawner capacity**	**Adjusted spawning capacity**
2.7	2,529.7	0.3125	12.4	0.1	31,368.28	9,803	980
2.8	2,541.39	0.3125	12.4	0.1	31,513.24	9,848	985
2.9	2,262.64	0.3125	12.4	0.1	28,056.74	8,768	877
3.0	2,352.92	0.3125	12.4	0.1	29,176.21	9,118	912
							3,754
2.7	2,529.7	0.1086	12.4	0.1	31,368.28	3,407	341
2.8	2,541.39	0.1086	12.4	0.1	31,513.24	3,422	342
2.9	2,262.64	0.1086	12.4	0.1	28,056.74	3,047	305
3.0	2,352.92	0.1086	12.4	0.1	29,176.21	3,169	317
							1,304
2.7	2,529.7	0.0781	12.4	0.1	31,368.28	2,450	245
2.8	2,541.39	0.0781	12.4	0.1	31,513.24	2,461	246
2.9	2,262.64	0.0781	12.4	0.1	28,056.74	2,191	219
3.0	2,352.92	0.0781	12.4	0.1	29,176.21	2,279	228
							938

Table A-6. Spawning habitat capacity of Section 2, predictive model 1. This model is based on the results of multiple regression analysis and utilizes the density of channel intersections to predict the number of spawning sites/strata. The adjusted spawning capacity is made up of pairs of adult chum salmon with the assumption of a 1:1 sex ratio. Total spawning pairs of all Section 2 strata, at each density are tallied in bold type.

Section 2							
Strata	**Strata length (m)**	**Spawning density/m^2**	**50% of average width(m)**	**Prediction of spawning**	**Spawning area (m^2)**	**Estimated spawner capacity**	**Adjusted spawning capacity**
2.7	2,529.7	0.3125	12.4	0.055882361	31,368.28	9,803	548
2.8	2,541.39	0.3125	12.4	0.04356618	31,513.236	9,848	429
2.9	2,262.64	0.3125	12.4	0.062040451	28,056.736	8,768	544
3.0	2,352.92	0.3125	12.4	0.03740809	29,176.208	9,118	341
							1,862
2.7	2,529.7	0.1086	12.4	0.055882361	31,368.28	3,407	190
2.8	2,541.39	0.1086	12.4	0.04356618	31,513.236	3,422	149
2.9	2,262.64	0.1086	12.4	0.062040451	28,056.736	3,047	189
3.0	2,352.92	0.1086	12.4	0.03740809	29,176.208	3,169	119
							647
2.7	2,529.7	0.0781	12.4	0.055882361	31,368.28	2,450	137
2.8	2,541.39	0.0781	12.4	0.04356618	31,513.236	2,461	107
2.9	2,262.64	0.0781	12.4	0.062040451	28,056.736	2,191	136
3.0	2,352.92	0.0781	12.4	0.03740809	29,176.208	2,279	85
							465

Table A-7. Spawning habitat capacity of Section 2, predictive model 2. Predictive model 2 is the lower bounds of a 95% confidence interval for the results of the regression equation between observed channel intersections and spawning site location. The model represents a remote sensing index that can be used to predict spawning capacity. Adjusted spawning capacity estimate is for pairs of adult salmon, assuming a 1:1 sex ratio. The totals of all Section 2 strata estimates at each density are listed in bold type.

Section 2							
Strata	Strata length (m)	Spawning density/m^2	50% of average width(m)	Prediction of spawning	Spawning area (m^2)	Estimated spawner capacity	Adjusted spawning capacity
2.7	2,529.7	0.3125	12.4	0.008306425	31,368.28	9,803	81
2.8	2,541.39	0.3125	12.4	0.006562675	31,513.24	9,848	65
2.9	2,262.64	0.3125	12.4	0.0091783	28,056.74	8,768	80
3.0	2,352.92	0.3125	12.4	0.0056908	29,176.21	9,118	52
							278
2.7	2,529.7	0.1086	12.4	0.008306425	31,368.28	3,407	28
2.8	2,541.39	0.1086	12.4	0.006562675	31,513.24	3,422	22
2.9	2,262.64	0.1086	12.4	0.0091783	28,056.74	3,047	28
3.0	2,352.92	0.1086	12.4	0.0056908	29,176.21	3,169	18
							97
2.7	2,529.7	0.0781	12.4	0.008306425	31,368.28	2,450	20
2.8	2,541.39	0.0781	12.4	0.006562675	31,513.24	2,461	16
2.9	2,262.64	0.0781	12.4	0.0091783	28,056.74	2,191	20
3.0	2,352.92	0.0781	12.4	0.0056908	29,176.21	2,279	13
							70

Table A-8. Spawning habitat capacity of Section 2, predictive model 3. Predictive model 3 is the upper bounds of a 95% confidence interval for the results of the regression equation between observed channel intersections and spawning site location. The model represents a remote sensing index that can be used to predict spawning capacity. Adjusted spawning capacity estimate is for pairs of adult salmon, assuming a 1:1 sex ratio. The totals of all Section 2 strata estimates at each density are listed in bold type.

Section 2							
Strata	Strata length (m)	Spawning density/m^2	50% of average width(m)	Prediction of spawning	Spawning area (m^2)	Estimated spawner capacity	Adjusted spawning capacity
2.7	2,529.7	0.3125	12.4	0.103458475	31,368.28	9,803	1,014
2.8	2,541.39	0.3125	12.4	0.080569825	31,513.24	9,848	793
2.9	2,262.64	0.3125	12.4	0.1149028	28,056.74	8,768	1,007
3.0	2,352.92	0.3125	12.4	0.0691255	29,176.21	9,118	630
							3,445
2.7	2,529.7	0.1086	12.4	0.103458475	31,368.28	3,407	352
2.8	2,541.39	0.1086	12.4	0.080569825	31,513.24	3,422	276
2.9	2,262.64	0.1086	12.4	0.1149028	28,056.74	3,047	350
3.0	2,352.92	0.1086	12.4	0.0691255	29,176.21	3,169	219
							1,197
2.7	2,529.7	0.0781	12.4	0.103458475	31,368.28	2,450	253
2.8	2,541.39	0.0781	12.4	0.080569825	31,513.24	2,461	198
2.9	2,262.64	0.0781	12.4	0.1149028	28,056.74	2,191	252
3.0	2,352.92	0.0781	12.4	0.0691255	29,176.21	2,279	158
							861

Table A-9. Spawning habitat capacity of Section 3, observed habitat model. Estimated spawning capacity of Section 3 was based on habitat characteristics and observations (incidence of spawning), at 3 different density levels.The total spawning capacity for all Section 3 strata at each density is listed in bold type as pairs of adult salmon (assuming a 1:1 sex ratio).

Section 3							
Strata	**Strata length (m)**	**Spawning density/m^2**	**50% of average width(m)**	**Incidence of spawning**	**Spawning Area (m^2)**	**Estimated spawner capacity**	**Adjusted spawning capacity**
3.1	2,374.99	0.3125	10.15	0.35	24,106.15	7,533	2637
3.2	1,779.37	0.3125	10.15	0.35	18,060.61	5,644	1975
3.3	2,474.86	0.3125	10.15	0.35	25,119.83	7,850	2747
3.4	2,487.62	0.3125	10.15	0.35	25,249.34	7,890	2762
							10,121
3.1	2,374.99	0.1086	10.15	0.35	24,106.15	2,618	916
3.2	1,779.37	0.1086	10.15	0.35	18,060.61	1,961	686
3.3	2,474.86	0.1086	10.15	0.35	25,119.83	2,728	955
3.4	2,487.62	0.1086	10.15	0.35	25,249.34	2,742	960
							3,517
3.1	2,374.99	0.0781	10.15	0.35	24,106.15	1,883	659
3.2	1,779.37	0.0781	10.15	0.35	18,060.61	1,411	494
3.3	2,474.86	0.0781	10.15	0.35	25,119.83	1,962	687
3.4	2,487.62	0.0781	10.15	0.35	25,249.34	1,972	690
							2,529

Table A-10. Spawning habitat capacity of Section 3, predictive model 1. This model is based on the results of multiple regression analysis and utilizes the density of channel intersections to predict the number of spawning sites/strata. The adjusted spawning capacity is made up of pairs of adult chum salmon with the assumption of a 1:1 sex ratio. Total spawning pairs of all Section 3 strata, at each density are listed in bold type.

Section 3							
Strata	**Strata length (m)**	**Spawning density/m^2**	**50% of average width(m)**	**Prediction of spawning**	**Spawning area (m^2)**	**Estimated spawner capacity**	**Adjusted spawning capacity**
3.1	2,374.99	0.3125	10.15	0.04356618	24,106.15	7,533	328
3.2	1,779.37	0.3125	10.15	0.062040451	18,060.61	5,644	350
3.3	2,474.86	0.3125	10.15	0.04356618	25,119.83	7,850	342
3.4	2,487.62	0.3125	10.15	0.055882361	25,249.34	7,890	441
							1,461
3.1	2,374.99	0.1086	10.15	0.04356618	24,106.15	2,618	114
3.2	1,779.37	0.1086	10.15	0.062040451	18,060.61	1,961	122
3.3	2,474.86	0.1086	10.15	0.04356618	25,119.83	2,728	119
3.4	2,487.62	0.1086	10.15	0.055882361	25,249.34	2,742	153
							508
3.1	2,374.99	0.0781	10.15	0.04356618	24,106.15	1,883	82
3.2	1,779.37	0.0781	10.15	0.062040451	18,060.61	1,411	88
3.3	2,474.86	0.0781	10.15	0.04356618	25,119.83	1,962	85
3.4	2,487.62	0.0781	10.15	0.055882361	25,249.34	1,972	110
							365

Table A-11. Spawning habitat capacity of Section 3, predictive model 2. Predictive model 2 is the lower bounds of a 95% confidence interval for the results of the regression equation between observed channel intersections and spawning site location. The model represents a remote sensing index that can be used to predict spawning capacity. Adjusted spawning capacity estimate is for pairs of adult salmon, assuming a 1:1 sex ratio. The totals of all Section 3 strata estimates at each density are listed in bold type.

Section 3

Strata	Strata length (m)	Spawning density/m^2	50% of average width(m)	Prediction of spawning	Spawning area (m^2)	Estimated spawner capacity	Adjusted spawning capacity
3.1	2,374.99	0.3125	10.15	0.006562675	24,106.15	7,533	49
3.2	1,779.37	0.3125	10.15	0.0091783	18,060.61	5,644	52
3.3	2,474.86	0.3125	10.15	0.006562675	25,119.83	7,850	52
3.4	2,487.62	0.3125	10.15	0.008306425	25,249.34	7,890	66
							218
3.1	2,374.99	0.1086	10.15	0.006562675	24,106.15	2,618	17
3.2	1,779.37	0.1086	10.15	0.0091783	18,060.61	1,961	18
3.3	2,474.86	0.1086	10.15	0.006562675	25,119.83	2,728	18
3.4	2,487.62	0.1086	10.15	0.008306425	25,249.34	2,742	23
							76
3.1	2,374.99	0.0781	10.15	0.006562675	24,106.15	1,883	12
3.2	1,779.37	0.0781	10.15	0.0091783	18,060.61	1,411	13
3.3	2,474.86	0.0781	10.15	0.006562675	25,119.83	1,962	13
3.4	2,487.62	0.0781	10.15	0.008306425	25,249.34	1,972	16
							55

Table A-12. Spawning habitat capacity of Section 3, predictive model 3. Predictive model 3 is the upper bounds of a 95% confidence interval for the results of the regression equation between observed channel intersections and spawning site location. The model represents a remote sensing index that can be used to predict spawning capacity. Adjusted spawning capacity estimate is for pairs of adult salmon, assuming a 1:1 sex ratio. The totals of all Section 3 strata estimates at each density are listed in bold type.

Section 3							
Strata	**Strata length (m)**	**Spawning density/m^2**	**50% of average width(m)**	**Prediction of spawning**	**Spawning area (m^2)**	**Estimated spawner capacity**	**Adjusted spawning capacity**
3.1	2,374.99	0.3125	10.15	0.080569825	24,106.15	7,533	607
3.2	1,779.37	0.3125	10.15	0.1149028	18,060.61	5,644	649
3.3	2,474.86	0.3125	10.15	0.080569825	25,119.83	7,850	632
3.4	2,487.62	0.3125	10.15	0.103458475	25,249.34	7,890	816
							2,704
3.1	2,374.99	0.1086	10.15	0.080569825	24,106.15	2,618	211
3.2	1,779.37	0.1086	10.15	0.1149028	18,060.61	1,961	225
3.3	2,474.86	0.1086	10.15	0.080569825	25,119.83	2,728	220
3.4	2,487.62	0.1086	10.15	0.103458475	25,249.34	2,742	284
							940
3.1	2,374.99	0.0781	10.15	0.080569825	24,106.15	1,883	152
3.2	1,779.37	0.0781	10.15	0.1149028	18,060.61	1,411	162
3.3	2,474.86	0.0781	10.15	0.080569825	25,119.83	1,962	158
3.4	2,487.62	0.0781	10.15	0.103458475	25,249.34	1,972	204
							676

Table A-13. Spawning habitat capacity of Section 4, observed habitat model. Estimated spawning capacity of Section 4 was based on habitat characteristics and observations (incidence of spawning), at 3 different density levels. The total spawning capacity for all Section 4 strata at each density is listed in bold type as pairs of adult salmon (assuming a 1:1 sex ratio).

Section 4							
Strata	**Strata length (m)**	**Spawning density/m^2**	**50% of average width(m)**	**Incidence of spawning**	**Spawning area (m^2)**	**Estimated spawner capacity**	**Adjusted spawning capacity**
3.5	2,133.06	0.3125	9.79	0.375	20,882.66	6,526	2,447
3.6	2,073.81	0.3125	9.79	0.375	20,302.60	6,345	2,379
3.7	1,679.98	0.3125	9.79	0.375	16,447.00	5,140	1,927
3.8	1,894.22	0.3125	9.79	0.375	18,544.41	5,795	2,173
							8,927
3.5	2,133.06	0.1086	9.79	0.375	20,882.66	2,268	850
3.6	2,073.81	0.1086	9.79	0.375	20,302.60	2,205	827
3.7	1,679.98	0.1086	9.79	0.375	16,447.00	1,786	670
3.8	1,894.22	0.1086	9.79	0.375	18,544.41	2,014	755
							3,102
3.5	2,133.06	0.0781	9.79	0.375	20,882.66	1,631	612
3.6	2,073.81	0.0781	9.79	0.375	20,302.60	1,586	595
3.7	1,679.98	0.0781	9.79	0.375	16,447.00	1,285	482
3.8	1,894.22	0.0781	9.79	0.375	18,544.41	1,448	543
							2,231

Table A-14. Spawning habitat capacity of Section 4, predictive model 1. This model is based on the results of multiple regression analysis and utilizes the density of channel intersections to predict the number of spawning sites/strata. The adjusted spawning capacity is made up of pairs of adult chum salmon with the assumption of a 1:1 sex ratio. Total spawning pairs of all Section 4 strata, at each density are listed in bold type.

Section 4

Strata	Strata length (m)	Spawning density/m^2	50% of average width(m)	Prediction of spawning	Spawning area (m^2)	Estimated spawner capacity	Adjusted spawning capacity
3.5	2,133.06	0.3125	9.79	0.04356618	20,882.66	6,526	284
3.6	2,073.81	0.3125	9.79	0.03125	20,302.60	6,345	198
3.7	1,679.98	0.3125	9.79	0.03740809	16,447.00	5,140	192
3.8	1,894.22	0.3125	9.79	0.055882361	18,544.41	5,795	324
							999
3.5	2,133.06	0.1086	9.79	0.04356618	20,882.66	2,268	99
3.6	2,073.81	0.1086	9.79	0.03125	20,302.60	2,205	69
3.7	1,679.98	0.1086	9.79	0.03740809	16,447.00	1,786	67
3.8	1,894.22	0.1086	9.79	0.055882361	18,544.41	2,014	113
							347
3.5	2,133.06	0.0781	9.79	0.04356618	20,882.66	1,631	71
3.6	2,073.81	0.0781	9.79	0.03125	20,302.60	1,586	50
3.7	1,679.98	0.0781	9.79	0.03740809	16,447.00	1,285	48
3.8	1,894.22	0.0781	9.79	0.055882361	18,544.41	1,448	81
							250

Table A-15. Spawning habitat capacity of Section 4, predictive model 2. Predictive model 2 is the lower bounds of a 95% confidence interval for the results of the regression equation between observed channel intersections and spawning site location. The model represents a remote sensing index that can be used to predict spawning capacity. Adjusted spawning capacity estimate is for pairs of adult salmon, assuming a 1:1 sex ratio. The totals of all Section 4 strata estimates at each density are listed in bold type.

Section 4							
Strata	Strata length (m)	Spawning density/m^2	50% of average width(m)	Prediction of spawning	Spawning area (m^2)	Estimated spawner capacity	Adjusted spawning capacity
3.5	2,133.06	0.3125	9.79	0.006562675	20,882.66	6,526	43
3.6	2,073.81	0.3125	9.79	0.004818925	20,302.60	6,345	31
3.7	1,679.98	0.3125	9.79	0.0056908	16,447.00	5,140	29
3.8	1,894.22	0.3125	9.79	0.008306425	18,544.41	5,795	48
							151
3.5	2,133.06	0.1086	9.79	0.006562675	20,882.66	2,268	15
3.6	2,073.81	0.1086	9.79	0.004818925	20,302.60	2,205	11
3.7	1,679.98	0.1086	9.79	0.0056908	16,447.00	1,786	10
3.8	1,894.22	0.1086	9.79	0.008306425	18,544.41	2,014	17
							52
3.5	2,133.06	0.0781	9.79	0.006562675	20,882.66	1,631	11
3.6	2,073.81	0.0781	9.79	0.004818925	20,302.60	1,586	8
3.7	1,679.98	0.0781	9.79	0.0056908	16,447.00	1,285	7
3.8	1,894.22	0.0781	9.79	0.008306425	18,544.41	1,448	12
							38

Table A-16. Spawning habitat capacity of Section 4, predictive model 3. Predictive model 3 is the upper bounds of a 95% confidence interval for the results of the regression equation between observed channel intersections and spawning site location. The model represents a remote sensing index that can be used to predict spawning capacity. Adjusted spawning capacity estimate is for pairs of adult salmon, assuming a 1:1 sex ratio. The totals of all Section 4 strata estimates at each density are listed in bold type.

Section 4							
Strata	**Strata length (m)**	**Spawning density/m^2**	**50% of average width(m)**	**Prediction of spawning**	**Spawning area (m^2)**	**Estimated spawner capacity**	**Adjusted spawning capacity**
3.5	2,133.06	0.3125	9.79	0.080569825	20,882.66	6,526	526
3.6	2,073.81	0.3125	9.79	0.057681175	20,302.60	6,345	366
3.7	1,679.98	0.3125	9.79	0.0691255	16,447.00	5,140	355
3.8	1,894.22	0.3125	9.79	0.103458475	18,544.41	5,795	600
							1,847
3.5	2,133.06	0.1086	9.79	0.080569825	20,882.66	2,268	183
3.6	2,073.81	0.1086	9.79	0.057681175	20,302.60	2,205	127
3.7	1,679.98	0.1086	9.79	0.0691255	16,447.00	1,786	123
3.8	1,894.22	0.1086	9.79	0.103458475	18,544.41	2,014	208
							642
3.5	2,133.06	0.0781	9.79	0.080569825	20,882.66	1,631	131
3.6	2,073.81	0.0781	9.79	0.057681175	20,302.60	1,586	91
3.7	1,679.98	0.0781	9.79	0.0691255	16,447.00	1,285	89
3.8	1,894.22	0.0781	9.79	0.103458475	18,544.41	1,448	150
							461

Table A-17. Spawning habitat capacity of Section 5, observed habitat model. Estimated spawning capacity of Section 5 was based on habitat characteristics and observations (incidence of spawning), at 3 different density levels. The total spawning capacity for all Section 5 strata at each density is listed in bold type as pairs of adult salmon (assuming a 1:1 sex ratio).

Section 5							
Strata	**Strata length (m)**	**Spawning density/m^2**	**50% of average width(m)**	**Incidence of spawning**	**Spawning area (m^2)**	**Estimated spawner capacity**	**Adjusted spawning capacity**
3.9	1,830.97	0.3125	13.31	0.15	24,370.21	7,616	1,142
4.0	2,012.88	0.3125	13.31	0.15	26,791.43	8,372	1,256
4.1	2,528.02	0.3125	13.31	0.15	33,647.95	10,515	1,577
4.2	1,991.98	0.3125	13.31	0.15	26,513.25	8,285	1,243
4.3	1,742.68	0.3125	13.31	0.15	23,195.07	7,248	1,087
4.4	1,644.03	0.3125	13.31	0.15	21,882.04	6,838	1,026
4.5	2,031.64	0.3125	13.31	0.15	27,041.13	8,450	1,268
							8,599
3.9	1,830.97	0.1086	13.31	0.15	24,370.21	2,647	397
4.0	2,012.88	0.1086	13.31	0.15	26,791.43	2,910	436
4.1	2,528.02	0.1086	13.31	0.15	33,647.95	3,654	548
4.2	1,991.98	0.1086	13.31	0.15	26,513.25	2,879	432
4.3	1,742.68	0.1086	13.31	0.15	23,195.07	2,519	378
4.4	1,644.03	0.1086	13.31	0.15	21,882.04	2,376	356
4.5	2,031.64	0.1086	13.31	0.15	27,041.13	2,937	440
							2,988
3.9	1,830.97	0.0781	13.31	0.15	24,370.21	1,903	285
4.0	2,012.88	0.0781	13.31	0.15	26,791.43	2,092	314
4.1	2,528.02	0.0781	13.31	0.15	33,647.95	2,628	394
4.2	1,991.98	0.0781	13.31	0.15	26,513.25	2,071	311
4.3	1,742.68	0.0781	13.31	0.15	23,195.07	1,812	272
4.4	1,644.03	0.0781	13.31	0.15	21,882.04	1,709	256
4.5	2,031.64	0.0781	13.31	0.15	27,041.13	2,112	317
							2,149

Table A-18. Spawning habitat capacity of Section 5, predictive model 1. This model is based on the results of multiple regression analysis and utilizes the density of channel intersections to predict the number of spawning sites/strata. The adjusted spawning capacity is made up of pairs of adult chum salmon with the assumption of a 1:1 sex ratio. Total spawning pairs of all Section 5 strata, at each density are listed in bold type.

Section 5							
Strata	**Strata length (m)**	**Spawning density/m^2**	**50% of average width(m)**	**Prediction of spawning**	**Spawning area (m^2)**	**Estimated spawner capacity**	**Adjusted spawning capacity**
3.9	1,830.97	0.3125	13.31	0.055882361	24,370.21	7,616	426
4.0	2,012.88	0.3125	13.31	0.01893382	26,791.43	8,372	159
4.1	2,528.02	0.3125	13.31	0.02509191	33,647.95	10,515	264
4.2	1,991.98	0.3125	13.31	0.02509191	26,513.25	8,285	208
4.3	1,742.68	0.3125	13.31	0.01277573	23,195.07	7,248	93
4.4	1,644.03	0.3125	13.31	0.01277573	21,882.04	6,838	87
4.5	2,031.64	0.3125	13.31	0.01893382	27,041.13	8,450	160
							1,396
3.9	1,830.97	0.1086	13.31	0.055882361	24,370.21	2,647	148
4.0	2,012.88	0.1086	13.31	0.01893382	26,791.43	2,910	55
4.1	2,528.02	0.1086	13.31	0.02509191	33,647.95	3,654	92
4.2	1,991.98	0.1086	13.31	0.02509191	26,513.25	2,879	72
4.3	1,742.68	0.1086	13.31	0.01277573	23,195.07	2,519	32
4.4	1,644.03	0.1086	13.31	0.01277573	21,882.04	2,376	30
4.5	2,031.64	0.1086	13.31	0.01893382	27,041.13	2,937	56
							485
3.9	1,830.97	0.0781	13.31	0.055882361	24,370.21	1,903	106
4.0	2,012.88	0.0781	13.31	0.01893382	26,791.43	2,092	40
4.1	2,528.02	0.0781	13.31	0.02509191	33,647.95	2,628	66
4.2	1,991.98	0.0781	13.31	0.02509191	26,513.25	2,071	52
4.3	1,742.68	0.0781	13.31	0.01277573	23,195.07	1,812	23
4.4	1,644.03	0.0781	13.31	0.01277573	21,882.04	1,709	22
4.5	2,031.64	0.0781	13.31	0.01893382	27,041.13	2,112	40
							349

Table A-19. Spawning habitat capacity of Section 5, predictive model 2. Predictive model 2 is the lower bounds of a 95% confidence interval for the results of the regression equation between observed channel intersections and spawning site location. The model represents a remote sensing index that can be used to predict spawning capacity. Adjusted spawning capacity estimate is for pairs of adult salmon, assuming a 1:1 sex ratio. The totals of all Section 5 strata estimates at each density are listed in bold type.

Section 5

Strata	Strata length (m)	Spawning density/m^2	50% of average width(m)	Prediction of spawning	Spawning area (m^2)	Estimated spawner capacity	Adjusted spawning capacity
3.9	1,830.97	0.3125	13.31	0.008306425	24,370.21	7,616	63
4.0	2,012.88	0.3125	13.31	0.003075175	26,791.43	8,372	26
4.1	2,528.02	0.3125	13.31	0.00394705	33,647.95	10,515	42
4.2	1,991.98	0.3125	13.31	0.00394705	26,513.25	8,285	33
4.3	1,742.68	0.3125	13.31	0.0022033	23,195.07	7,248	16
4.4	1,644.03	0.3125	13.31	0.0022033	21,882.04	6,838	15
4.5	2,031.64	0.3125	13.31	0.003075175	27,041.13	8,450	26
							220
3.9	1,830.97	0.1086	13.31	0.008306425	24,370.21	2,647	22
4.0	2,012.88	0.1086	13.31	0.003075175	26,791.43	2,910	9
4.1	2,528.02	0.1086	13.31	0.00394705	33,647.95	3,654	14
4.2	1,991.98	0.1086	13.31	0.00394705	26,513.25	2,879	11
4.3	1,742.68	0.1086	13.31	0.0022033	23,195.07	2,519	6
4.4	1,644.03	0.1086	13.31	0.0022033	21,882.04	2,376	5
4.5	2,031.64	0.1086	13.31	0.003075175	27,041.13	2,937	9
							77
3.9	1,830.97	0.0781	13.31	0.008306425	24,370.21	1,903	16
4.0	2,012.88	0.0781	13.31	0.003075175	26,791.43	2,092	6
4.1	2,528.02	0.0781	13.31	0.00394705	33,647.95	2,628	10
4.2	1,991.98	0.0781	13.31	0.00394705	26,513.25	2,071	8
4.3	1,742.68	0.0781	13.31	0.0022033	23,195.07	1,812	4
4.4	1,644.03	0.0781	13.31	0.0022033	21,882.04	1,709	4
4.5	2,031.64	0.0781	13.31	0.003075175	27,041.13	2,112	6
							55

Table A-20. Spawning habitat capacity of Section 5, predictive model 3. Predictive model 3 is the upper bounds of a 95% confidence interval for the results of the regression equation between observed channel intersections and spawning site location. The model represents a remote sensing index that can be used to predict spawning capacity. Adjusted spawning capacity estimate is for pairs of adult salmon, assuming a 1:1 sex ratio. The totals of all Section 5 strata estimates at each density are listed in bold type.

Section 5							
Strata	**Strata length (m)**	**Spawning density/m^2**	**50% of average width(m)**	**Prediction of spawning**	**Spawning area (m^2)**	**Estimated spawner capacity**	**Adjusted spawning capacity**
3.9	1,830.97	0.3125	13.31	0.103458475	24,370.21	7,616	788
4.0	2,012.88	0.3125	13.31	0.034792525	26,791.43	8,372	291
4.1	2,528.02	0.3125	13.31	0.04623685	33,647.95	10,515	486
4.2	1,991.98	0.3125	13.31	0.04623685	26,513.25	8,285	383
4.3	1,742.68	0.3125	13.31	0.0233482	23,195.07	7,248	169
4.4	1,644.03	0.3125	13.31	0.0233482	21,882.04	6,838	160
4.5	2,031.64	0.3125	13.31	0.034792525	27,041.13	8,450	294
							2,571
3.9	1,830.97	0.1086	13.31	0.103458475	24,370.21	2,647	274
4.0	2,012.88	0.1086	13.31	0.034792525	26,791.43	2,910	101
4.1	2,528.02	0.1086	13.31	0.04623685	33,647.95	3,654	169
4.2	1,991.98	0.1086	13.31	0.04623685	26,513.25	2,879	133
4.3	1,742.68	0.1086	13.31	0.0233482	23,195.07	2,519	59
4.4	1,644.03	0.1086	13.31	0.0233482	21,882.04	2,376	55
4.5	2,031.64	0.1086	13.31	0.034792525	27,041.13	2,937	102
							894
3.9	1,830.97	0.0781	13.31	0.103458475	24,370.21	1,903	197
4.0	2,012.88	0.0781	13.31	0.034792525	26,791.43	2,092	73
4.1	2,528.02	0.0781	13.31	0.04623685	33,647.95	2,628	122
4.2	1,991.98	0.0781	13.31	0.04623685	26,513.25	2,071	96
4.3	1,742.68	0.0781	13.31	0.0233482	23,195.07	1,812	42
4.4	1,644.03	0.0781	13.31	0.0233482	21,882.04	1,709	40
4.5	2,031.64	0.0781	13.31	0.034792525	27,041.13	2,112	73
							643

Table A-21. **Spawning habitat capacity of Section 6, observed habitat model. Estimated spawning capacity of Section 6 was based on habitat characteristics and observations (incidence of spawning), at 3 different density levels. The total spawning capacity for all Section 6 strata at each density is listed in bold type as pairs of adult salmon (assuming a 1:1 sex ratio).**

Section 6

Strata	Strata length (m)	Spawning density/m^2	50% of average width(m)	Incidence of spawning	Spawning area (m^2)	Estimated spawner capacity	Adjusted spawning capacity
4.6	1,519.53	0.3125	16.25	0.025	24,692.36	7,716	193
4.7	1,711.02	0.3125	16.25	0.025	27,804.08	8,689	217
4.8	2,006.05	0.3125	16.25	0.025	32,598.31	10,187	255
4.9	2,123.81	0.3125	16.25	0.025	34,511.91	10,785	270
5.0	2,273.89	0.3125	16.25	0.025	36,950.71	11,547	289
5.1	2,489.44	0.3125	16.25	0.025	40,453.40	12,642	316
5.2	2,126.69	0.3125	16.25	0.025	34,558.71	10,800	270
							1,809
4.6	1,519.53	0.1086	16.25	0.025	24,692.36	2,682	67
4.7	1,711.02	0.1086	16.25	0.025	27,804.08	3,020	75
4.8	2,006.05	0.1086	16.25	0.025	32,598.31	3,540	89
4.9	2,123.81	0.1086	16.25	0.025	34,511.91	3,748	94
5.0	2,273.89	0.1086	16.25	0.025	36,950.71	4,013	100
5.1	2,489.44	0.1086	16.25	0.025	40,453.40	4,393	110
5.2	2,126.69	0.1086	16.25	0.025	34,558.71	3,753	94
							629
4.6	1,519.53	0.0781	16.25	0.025	24,692.36	1,928	48
4.7	1,711.02	0.0781	16.25	0.025	27,804.08	2,171	54
4.8	2,006.05	0.0781	16.25	0.025	32,598.31	2,546	64
4.9	2,123.81	0.0781	16.25	0.025	34,511.91	2,695	67
5.0	2,273.89	0.0781	16.25	0.025	36,950.71	2,886	72
5.1	2,489.44	0.0781	16.25	0.025	40,453.40	3,159	79
5.2	2,126.69	0.0781	16.25	0.025	34,558.71	2,699	67
							452

Table A-22. Spawning habitat capacity of Section 6, predictive model 1. This model is based on the results of multiple regression analysis and utilizes the density of channel intersections to predict the number of spawning sites/strata. The adjusted spawning capacity is made up of pairs of adult chum salmon with the assumption of a 1:1 sex ratio. Total spawning pairs of all Section 6 strata, at each density are listed in bold type.

Section 6

Strata	Strata length (m)	Spawning density/m^2	50% of average width(m)	Prediction of spawning	Spawning area (m^2)	Estimated spawner capacity	Adjusted spawning capacity
4.6	1,519.53	0.3125	16.25	0.03125	24,692.36	7,716	241
4.7	1,711.02	0.3125	16.25	0.02509191	27,804.08	8,689	218
4.8	2,006.05	0.3125	16.25	0.03125	32,598.31	10,187	318
4.9	2,123.81	0.3125	16.25	0.02509191	34,511.91	10,785	271
5.0	2,273.89	0.3125	16.25	0.006617639	36,950.71	11,547	76
5.1	2,489.44	0.3125	16.25	0.01277573	40,453.40	12,642	162
5.2	2,126.69	0.3125	16.25	0.01893382	34,558.71	10,800	204
							1,491
4.6	1,519.53	0.1086	16.25	0.03125	24,692.36	2,682	84
4.7	1,711.02	0.1086	16.25	0.02509191	27,804.08	3,020	76
4.8	2,006.05	0.1086	16.25	0.03125	32,598.31	3,540	111
4.9	2,123.81	0.1086	16.25	0.02509191	34,511.91	3,748	94
5.0	2,273.89	0.1086	16.25	0.006617639	36,950.71	4,013	27
5.1	2,489.44	0.1086	16.25	0.01277573	40,453.40	4,393	56
5.2	2,126.69	0.1086	16.25	0.01893382	34,558.71	3,753	71
							518
4.6	1,519.53	0.0781	16.25	0.03125	24,692.36	1,928	60
4.7	1,711.02	0.0781	16.25	0.02509191	27,804.08	2,171	54
4.8	2,006.05	0.0781	16.25	0.03125	32,598.31	2,546	80
4.9	2,123.81	0.0781	16.25	0.02509191	34,511.91	2,695	68
5.0	2,273.89	0.0781	16.25	0.006617639	36,950.71	2,886	19
5.1	2,489.44	0.0781	16.25	0.01277573	40,453.40	3,159	40
5.2	2,126.69	0.0781	16.25	0.01893382	34,558.71	2,699	51
							373

Table A-23. Spawning habitat capacity of Section 6, predictive model 2. Predictive model 2 is the lower bounds of a 95% confidence interval for the results of the regression equation between observed channel intersections and spawning site location. The model represents a remote sensing index that can be used to predict spawning capacity. Adjusted spawning capacity estimate is for pairs of adult salmon, assuming a 1:1 sex ratio. The totals of all Section 6 strata estimates at each density are listed in bold type.

Section 6							
Strata	**Strata length (m)**	**Spawning density/m^2**	**50% of average width(m)**	**Prediction of spawning**	**Spawning area (m^2)**	**Estimated spawner capacity**	**Adjusted spawning capacity**
4.6	1,519.53	0.3125	16.25	0.004818925	24,692.36	7,716	37
4.7	1,711.02	0.3125	16.25	0.00394705	27,804.08	8,689	34
4.8	2,006.05	0.3125	16.25	0.004818925	32,598.31	10,187	49
4.9	2,123.81	0.3125	16.25	0.00394705	34,511.91	10,785	43
5.0	2,273.89	0.3125	16.25	0.001331425	36,950.71	11,547	15
5.1	2,489.44	0.3125	16.25	0.0022033	40,453.40	12,642	28
5.2	2,126.69	0.3125	16.25	0.003075175	34,558.71	10,800	33
							240
4.6	1,519.53	0.1086	16.25	0.004818925	24,692.36	2,682	13
4.7	1,711.02	0.1086	16.25	0.00394705	27,804.08	3,020	12
4.8	2,006.05	0.1086	16.25	0.004818925	32,598.31	3,540	17
4.9	2,123.81	0.1086	16.25	0.00394705	34,511.91	3,748	15
5.0	2,273.89	0.1086	16.25	0.001331425	36,950.71	4,013	5
5.1	2,489.44	0.1086	16.25	0.0022033	40,453.40	4,393	10
5.2	2,126.69	0.1086	16.25	0.003075175	34,558.71	3,753	12
							83
4.6	1,519.53	0.0781	16.25	0.004818925	24,692.36	1,928	9
4.7	1,711.02	0.0781	16.25	0.00394705	27,804.08	2,171	9
4.8	2,006.05	0.0781	16.25	0.004818925	32,598.31	2,546	12
4.9	2,123.81	0.0781	16.25	0.00394705	34,511.91	2,695	11
5.0	2,273.89	0.0781	16.25	0.001331425	36,950.71	2,886	4
5.1	2,489.44	0.0781	16.25	0.0022033	40,453.40	3,159	7
5.2	2,126.69	0.0781	16.25	0.003075175	34,558.71	2,699	8
							60

Table A-24. Spawning habitat capacity of Section 6, predictive model 3. Predictive model 3 is the upper bounds of a 95% confidence interval for the results of the regression equation between observed channel intersections and spawning site location. The model represents a remote sensing index that can be used to predict spawning capacity. Adjusted spawning capacity estimate is for pairs of adult salmon, assuming a 1:1 sex ratio. The totals of all Section 6 strata estimates at each density are listed in bold type.

Section 6							
Strata	Strata length (m)	Spawning density/m^2	50% of average width(m)	Prediction of spawning	Spawning area (m^2)	Estimated spawner capacity	Adjusted spawning capacity
4.6	1,519.53	0.3125	16.25	0.103458475	24,692.36	7,716	788
4.7	1,711.02	0.3125	16.25	0.034792525	27,804.08	8,689	291
4.8	2,006.05	0.3125	16.25	0.04623685	32,598.31	10,187	486
4.9	2,123.81	0.3125	16.25	0.04623685	34,511.91	10,785	383
5.0	2,273.89	0.3125	16.25	0.0233482	36,950.71	11,547	169
5.1	2,489.44	0.3125	16.25	0.0233482	40,453.40	12,642	160
5.2	2,126.69	0.3125	16.25	0.034792525	34,558.71	10,800	294
							2,571
4.6	1,519.53	0.1086	16.25	0.103458475	24,692.36	2,682	274
4.7	1,711.02	0.1086	16.25	0.034792525	27,804.08	3,020	101
4.8	2,006.05	0.1086	16.25	0.04623685	32,598.31	3,540	169
4.9	2,123.81	0.1086	16.25	0.04623685	34,511.91	3,748	133
5.0	2,273.89	0.1086	16.25	0.0233482	36,950.71	4,013	59
5.1	2,489.44	0.1086	16.25	0.0233482	40,453.40	4,393	55
5.2	2,126.69	0.1086	16.25	0.034792525	34,558.71	3,753	102
							894
4.6	1,519.53	0.0781	16.25	0.103458475	24,692.36	1,928	197
4.7	1,711.02	0.0781	16.25	0.034792525	27,804.08	2,171	73
4.8	2,006.05	0.0781	16.25	0.04623685	32,598.31	2,546	122
4.9	2,123.81	0.0781	16.25	0.04623685	34,511.91	2,695	96
5.0	2,273.89	0.0781	16.25	0.0233482	36,950.71	2,886	42
5.1	2,489.44	0.0781	16.25	0.0233482	40,453.40	3,159	40
5.2	2,126.69	0.0781	16.25	0.034792525	34,558.71	2,699	73
							643